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CHAPTER 1

UNIT I

Design, Management Auditing of Electrical System

Syllabus

Types of electrical Projects, Types of electrical system, review of components of electrical system, different plans/ drawings in electrical system design, single line diagram in detail,

Objectives

After studying the chapter you will be able to

- Understand the types of electrical projects
- Understand the types of electrical systems
- Know the major components of electrical systems
- Know the different plans / drawings in electric system design
- Know the single line diagram

1.1 Types of Electrical Projects

Electrical projects are classified into two basic types :

1. Hardware based projects
2. Software based projects

1.1.1 Hardware Based Projects

Hardware based projects are basically core electrical, electronic and embedded electrical projects. Sometimes hardware projects are used with trial and error approach to achieve best results.

Hardware projects are related to

- Testing and development of electrical machines involving induction motor, synchronous motors, BLDC motors etc. as they are used more frequently in industrial applications.

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- Switchgear and protections projects are developed involving use of relay.
- Development of process control units with electronic devices consisting FACTS, UPFC, SVPWM, MOSFET, IGBT, SCR, TRIAC etc.
- Microprocessor or Microcontroller having OPAMP, 8051, 8085, 8086.
- Electrical testing of materials, machines, devices etc. for reliability analysis.
- Industrial automations using SCADA, PLC etc.
- Renewable energy projects involving solar panels, wind machines etc.
- Electrical battery manufacturing and testing
- Robots and robotic control
- Electrical drives and control with various methods

1.1.2 Software Based Projects

Software based projects are useful in designing electrical system and components before their uses, with cost effectiveness calculation. Software are validating results before the actual implementation like :

1. Behaviour of electrical components and systems during short circuit and faults,
2. Load flow calculations before supply of power to avoid load congestion, and load shedding or faulty operation,
3. Protective device evaluation and co-ordinations,
4. Lighting system design,
5. Arc flash analysis and calculation,
6. Harmonic analysis to reduce distortion of current and voltage waveforms,
7. Motor starting studies
8. Behavior of non-linear loads, etc.
9. Energy management system for reliable operation

Software based projects are using mathematical support with the help of probabilistic and deterministic approach. These software projects provides base for electrical hardware development.

In electrical projects following softwares are most commonly used

- Matlab
- Fuzzy logic control
- Digital Signal Processing (DSP)
- Artificial Neural Network (ANN)
- E-Tap
- Lab View
- Minitab
- Q Blade
- WAsP
- Excel
- C and C++ for code development
- Java for programming
- PSCAD
- Auto CAD
- Easy Power
- Windsim
- HOMER
- Solaripedia
- Wind Pro

1.2 Types of Electrical System

Electrical systems are mainly classified as

1)	Power generation system	2)	Power transmission system
3)	Power distribution system	4)	Earthing system
5)	Energy storage system	6)	Electrical wiring system

1. Power generation system

It involves generator, turbine, protective equipments, generator substation, etc.. Now days power is generated at 33 or 22 or 11 kV voltage level.

2. Power transmission system

Power is transmitted at 220 kV or 110 kV or 66 kV voltage level. Power transmission system mainly consist of step up transformer, toner, electrical conductors and other equipments like insulators, circuit breakers etc.

3. Power distribution system

Power is distributed to the consumers at 33 or 22 or 11 kV voltage level. It basically consists of step down transformer, distribution feeders. Here power is actually distributed from three wire or four wire system.

4. Earthing system

In earthing system metallic parts, electrical equipments and installations are connected to the ground therefore it is called as earthing. Main aim of earthing is to avoid or minimize the danger of electrocution or fine due to leakage current in normal or fault operation.

Earthing system is of five types

(a)	Plate earthing	(b)	Rod earthing
(c)	Pipe earthing	(d)	Wire earthing
(e)	Equipment earthing		

(a) Plate earthing

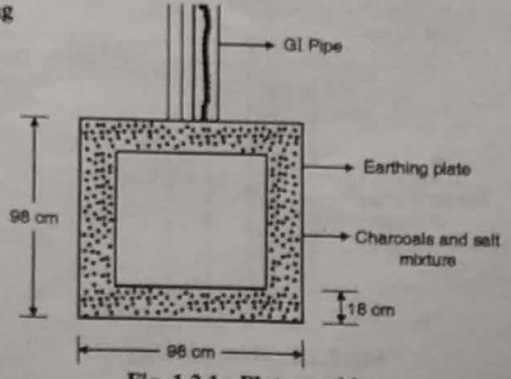

Fig. 1.2.1 : Plate earthing

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(b) **Rod earthing**

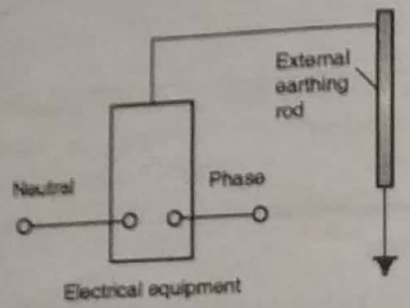

Fig. 1.2.2 : Rod earthing

(c) **Pipe earthing**

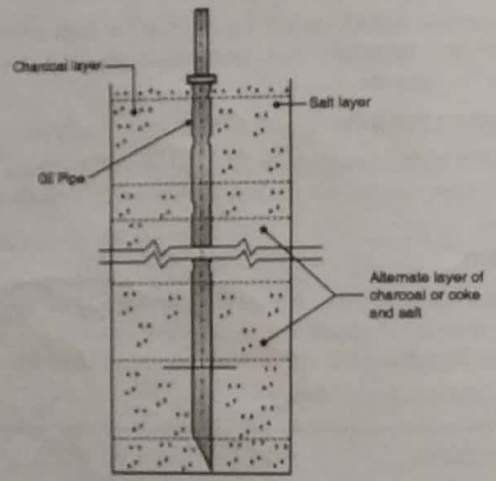

Fig. 1.2.3 : Pipe earthing

(d) **Wire earthing**

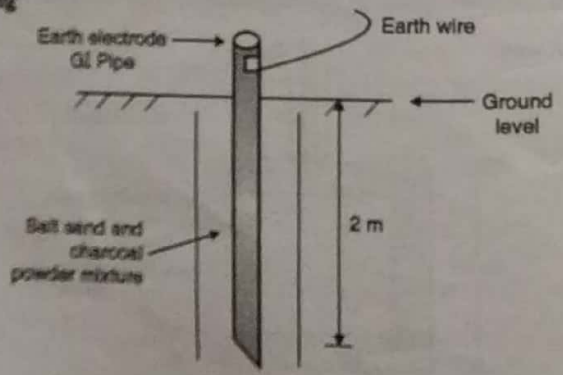

Fig. 1.2.4 : Wire earthing

(e) **Equipment earthing**

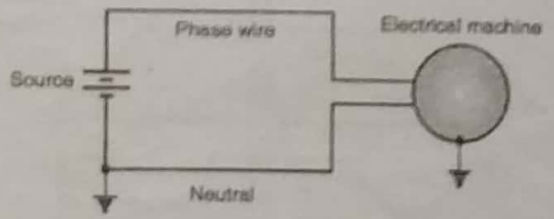

Fig. 1.2.5 : Equipment earthing

5. Energy storage systems :

To use electrical energy properly it should be stored in some form. The energy storage system is classified into following types :

- Thermal energy storage
- Electrical storage
- Chemical storage
- Mechanical energy storage
- Electromagnetic energy storage

Fig. 1.2.6 shows typical energy storage system classification :

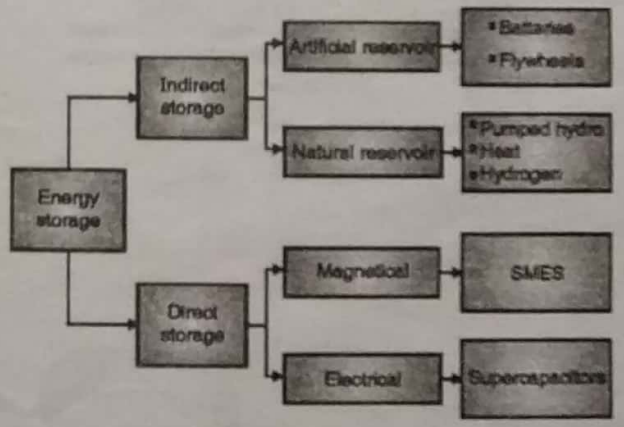

Fig. 1.2.6 : Energy storage system

6. Electrical wiring system

Most commonly used wiring systems for residential and commercial building are :

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- **Cleat wiring system**

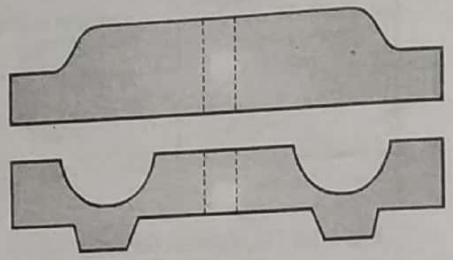

Fig. 1.2.7

- **Wooden casing and capping wiring system**

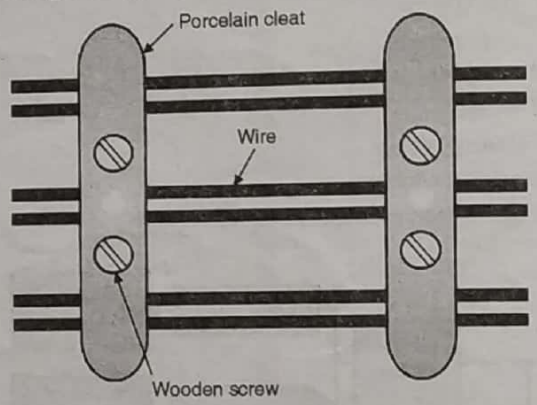

Fig. 1.2.8

- **Pipe wiring system**
- **Conduct wiring system**

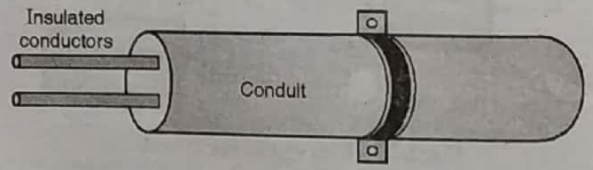

Fig. 1.2.9

In conduct wiring system, black conducts pipes are mounted on the walls. These conduct pipes carry electrical wires using capping pins. The disadvantages of this method are use of black colours pipes gives bad appearance on walls and mechanical strength of these pipes are less.

- **Batten wiring system**

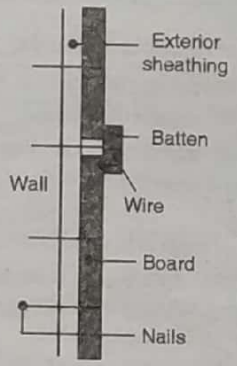

Fig. 1.2.10

In Batten wiring system, wooden plates are mounted on the walls. These wooden plates carry electrical wires using capping pins. Disadvantage of this method is that it allows moisturised air comes directly in contact with current carrying wires.

- **Concealed wiring system**

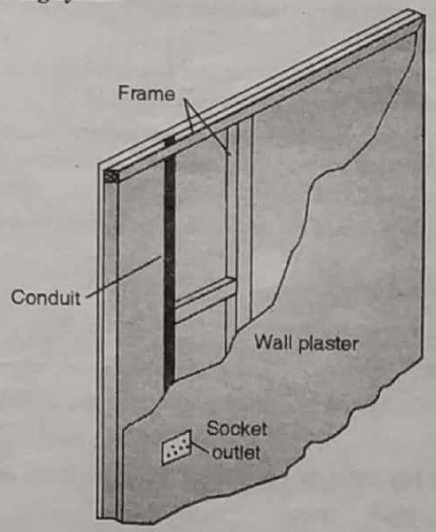

Fig. 1.2.11

In case of Concealed wiring system, all electrical wires and wiring system are firmly fitted in to the walls. Disadvantage of this method is that in case of short circuit or damage of any wire we have to replace entire wire. For replacement we have to broke entire wall resulting into large cost of replacement.

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1.3 General Review of Components of Electrical System

Major components of electrical system are described as follows:

- **Generator :** To generate power for serving purposes e.g. Unified Power Supply (UPS)
- **Underground cables :** it is used to transmit the power
- **Transformer :** It is a device who transfers power from one voltage level to another without change of frequency. They are used to step-up or step down the power supply at desired voltage level.
- **Towers :** They provide mechanical support to conductors caring power.
- **Conductors :** They are used to transfer the power from power to the consumer premises. Mainly copper, aluminium, Aluminium Alloy Conductor (AAC), Aluminium Conductor Steel Reinforced (ACSR) are used as a conducting material.
- **Loads :** Load are classified as :
  - (1) **Resistive load :** e.g. Lamp, tubes, CFL, LED
  - (2) **Inductive load :** e.g. Electrical motor, solenoids and relays etc.
  - (3) **Capacitive load :** e.g. Capacitor
- **Inverter :** It is used to converter the dc supply into ac supply
- **Energy meters :** They are used to measure the amount of electrical energy consumed by the customer. Nowadays digitalised energy meters are used to avoid the losses due to the power theft by tampering the meters.
- **Busbar :** They are used to transfer the power from switch board, distribution board, substation etc. Mainly copper or aluminium busbars are commonly used.
- **Fuses :** They are used to prevent large amount of current following through the electrical equipments. Mainly copper, aluminium, silver, constantan, nichrome are used as a fuse materials. Commonly used fuses are kit-kat fuse, glass fuse, high rupturing capacity (HRC) fuse etc.
- **Circuit breakers :** Circuit breakers are used for over current protection. Most commonly use circuit breakers are :
  - *Miniature circuit breaker*
  - *SF6 gas circuit breaker*
  - *Air circuit breaker*
- **Meters :** Mainly ammeters, voltmeters and energy metes are used to measure current, voltage and power respectively.
- **Switches :** They are used to control the circuit operations. Basically they are of following types :
  - (1) *Single Pole Single Throw (SPST)*
  - (2) *Single Pole Double Throw (SPDT)*
  - (3) *Double Pole Single Throw (DPST)*
  - (4) *Double Pole Double Throw (DPDT)*
  - (5) *Ganged switch*
  - (6) *Pressure / Temperature / Position activate*

- **Batteries :** It is utilized to store the electrical energy for a period of time. Most commonly used batteries are :
  - (1) Lithium Ion batteries
  - (2) Nickel Cadmium batteries
  - (3) Lead acid batteries
  - (4) Nickel metal hydride batteries

1.4 Single line Diagram

Single line diagrams are used to show or represent the 3 phase power system components with their ratings and size. Single line diagram provides detail information of power system components at a moment in time.

Single line diagrams are used in many important types of function including

- Short circuit calculation
- Load flow studies
- Maintenance
- Electrical safety evaluation

Fig. 1.4.1 shows single line diagram of 111/33 kV substation

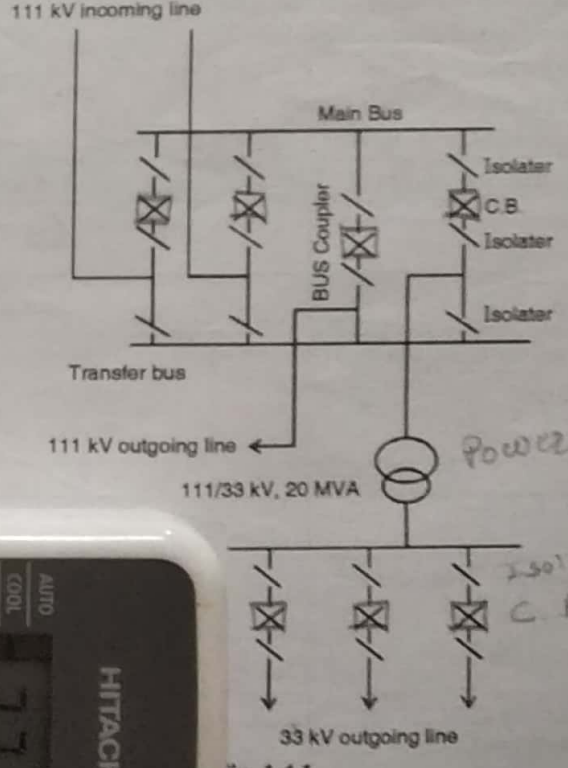

Fig. 1.4.1

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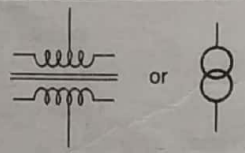
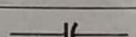
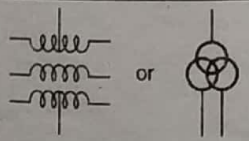
Single line diagram provides following information

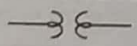
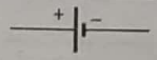
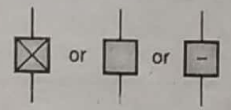
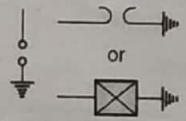
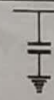
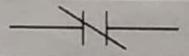
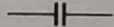
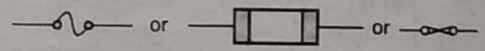
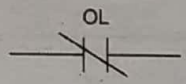
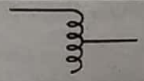
- Incoming lines, their size, voltage and rating etc.
- Rating and physical locations of fuses, switches tie lines, tie breakers, busbars, capacitors and transformers etc.
- Manufacturers type designations and ratings of devices.
- Relays, their functions, types, size, voltage and rating etc.
- Current and potential transformer - their size, type and ratio etc.
- Power and distribution transformers - their size, rating, type, class, taps, connections etc.
- Cable or conductor sizes and length
- Substation with rating and voltage levels
- Load on each feeder and on each substation
- Metered points and type of metering
- Switch and fuse ratings in volts and amperes.
- Critical equipments – voltage and size e.g. UPS, generators, Power distribution, computer room.

Advantages of single line diagrams

- It helps in identifying faults easily
- Ensure safety of working personnel
- Provide safe and reliable operations of power system
- To improve performance of electrical services.
- Easy to describe the circuit diagram
- It can be read and understand working easily.

Some of the standard symbols used to represent substation components are given below :

Sr. No.	Electrical components	Symbol
1.	AC Generator	
2.	Bus bar	
3.	Power transformer (two winding)	
4.	Capacitor	
5.	Power transformer (three winding)	
6.	Current transformer	

Sr. No.	Electrical components	Symbol
7.	Blowout coil	
8.	Potential transformer	
9.	Battery	
10.	Circuit breaker	
11.	Isolator	
12.	Lighting Arrestor (LA)	
13.	Coupling Capacitor	
14.	Normally closed contact	
15.	Normally open contact	
16.	Fuse	
17.	Overload relay	
18.	Synchronous motor	
19.	Auto transformer	

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Sr. No.	Electrical components	Symbol
20.	Load	
21.	Wave or line trap	
22.	Diode	
23.	SCR	
24.	Triac	
25.	SPST	
26.	DPST	
27.	SPDT	
28.	DPDT	

1.5 Different Plans / Drawing in Electrical System Design

Plants / drawings are classified into following types :

- Wiring or connection diagram
- Logic diagram
- Controller diagram

- Block diagram
- Dimension or outline drawing
- Layout drawings
- Control system diagram
- Control sequence diagram
- Foundation drawings
- Construction diagram
- Illustrative diagram
- Interconnection diagram
- Process / Flow diagram
- Elementary diagram
- Connection diagram (Wireless also)

Forms of diagrams or drawings

Diagrams or drawings are considered to be any one of forms :

- Block diagram
- Single line or one line diagram
- Logic diagram.

Review Questions

Q. 1 Describe general types of electrical Projects

Q. 2 Describe the review of components of electrical system

Q. 3 State different plans/ drawings in electrical system design

Q. 4 Explain single line diagram in detail,

❑❑❑

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UNIT II

CHAPTER 2

Design of Power Distribution System

Syllabus :

Different types of distribution systems and selection criteria, temporary and permanent power supply, electrical load size, L.F, D.F, future estimates, substation equipment's options, design considerations in transformer selection, sizing and specifications, IS standards applicable in above design

Objectives

After studying the chapter you will be able to :

- Understand the types of electrical distribution systems and their selection criteria
- Understand the temporary and permanent power supply
- Know the load factor and diversity factor
- Know the different design considerations in transformer selection
- Know the IS standards applicable in design of power distribution system

2.1 Introduction

- Designing a power distribution system the following considerations or goals must be taken into account
- Lower capital cost Capital cost is needed for purchasing the land, equipments, building development etc.
- Reliable power supply for current and future need - in general reliability of electrical supply can be increased by
  - Utilizing multiple utility power sources
  - Choosing preventative and protective maintenance systems
  - Having multiple service connection paths to the load area
  - Using proper and accurate installation methods
  - Using short-time rated circuit breakers
  - Using good alarms, monitoring and diagnostics systems
  - Allowing customer owned power sources such as generators or batteries giving uninterruptable power supply
  - Using high quality electrical components and conductors

Lower operating cost

- Lower operating cost can be achieved by increasing operating efficiency. For that purpose we have to minimize the losses in conductors, transformers and utilization equipment. Proper voltage level selection is also affect the operating cost.
- Flexible electrical network
- Flexible electrical network is needed for future building expansion, increased load requirements, for increased unexpected loads, for additional protective devices, power monitoring communication systems connected to electronic meters.

Safety of working personnel

- Design of distribution system must guarantee the safety of working personnel and the system equipment's during normal, emergency and maintenance operations. During designing process NEC and NFPA electricity codes must be obeyed.
- Minimize the maintenance cost
- For minimizing maintenance cost simple design of electrical network is required. Draw out type protective devices should be used to lower down the maintenance cost.

Types of lighting systems

- It depends upon the use, type, shape and size of building.
- High efficiency
- Locations of distribution equipment, characteristics of loads, locations of substations
- Simplicity of design
- Basic structure for present and future expansion
- Demand and diversity factor of loads
- Sources of power - base, standby and emergency
- Energy management
- Distribution and utilization voltages
- Bus and cable feeders
- Distribution equipment and motor control centre
- Power and lighting panel boards and motor control centres
- Installation methods used
- Power monitoring systems
- Electric utility requirements

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2.2 Different Types of Distribution Systems and Selection Criteria

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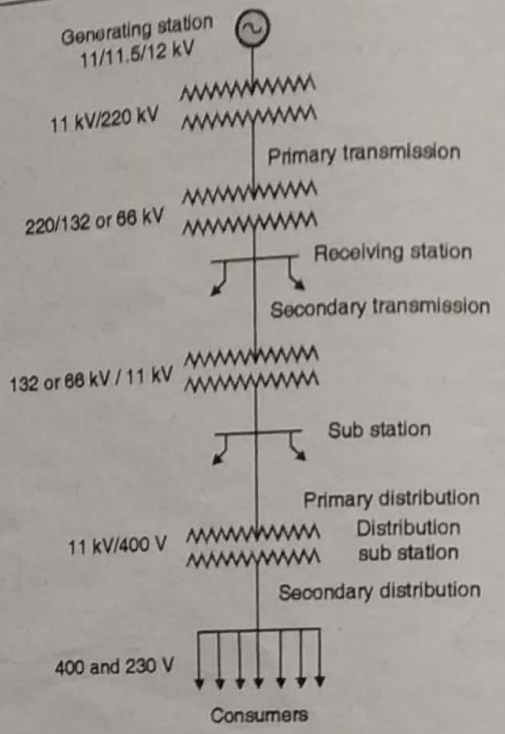

Fig. 2.2.1

- In Indian power sector, electrical systems are divided into three types
  - Generation system,
  - Transmission system and
  - Distribution system
- Figure shows typical ac power supply system. Distribution system connects the distribution substation to the customer. Fig show general diagram of substation and distribution system.

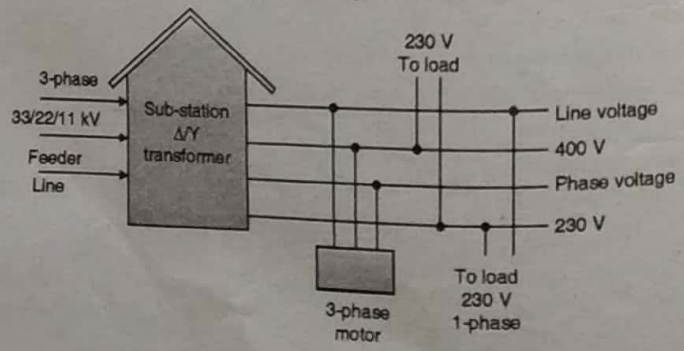

Fig. 2.2.2

General classification of distribution system is given in fig.2.2.3

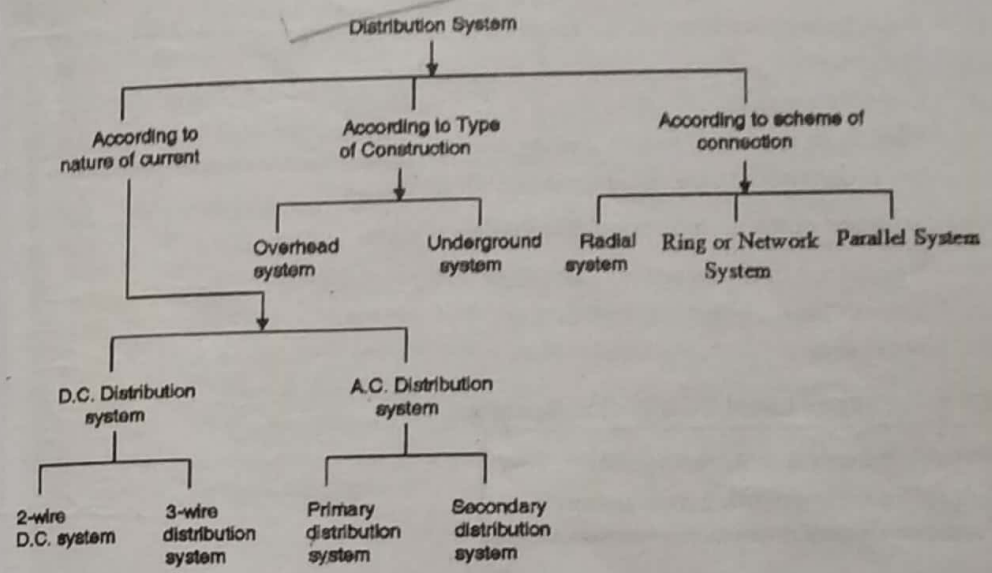

Fig. 2.2.3

2.2.1 Types of Distribution Systems

Distribution systems are classified into two types depending on the construction.

(1) Overhead distribution system

(2) Underground distribution system

Advantages of overhead distribution system

(1) It is very easy to find out the fault and to repair it.

(2) Fault detection is very easy.

(3) In case of fault replacing conductor is easy.

Disadvantages of overhead distribution system

Disadvantages of overhead distribution system :

(1) It has more power outages.

(2) Less reliable

(3) Less costly

(4) As they operate under continuously varying climate condition some time they get failed due to corrosion, mechanical wear and tear etc.

(5) Due to more reactance larger voltage drop occur.

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Advantages of underground distribution system

(1) Maintenance cost is less
(2) Power Transmission losses are less due to use of large size conductors
(3) More reliable
(4) Lower voltage drops
(5) Cable laying require less time i.e. erection time
(6) Due to underground cable visual appearance not get affected.

Disadvantages of the underground distribution system

(1) It require special equipments to locate a fault,
(2) It require larger cost and time for repair fault
(3) More costly

2.2.2 Voltage Level Distribution Systems

(1) Primary distribution system
(2) Secondary distribution system

(1) Primary distribution system :

Primary distribution system voltage level is 33/22/11 KV. In primary distribution system, all primary distribution feeder are joined together to form a mesh or primary grid. This mesh or primary grid is supplied from many sub-transmission or transmission transformers having rating of 220/ 110/ 66 kV / 33/22/11 kV.

(2) Secondary distribution system

- Secondary distribution system voltage level is 0.4 KV which can call as utilization voltage. In secondary distribution system mainly delta to star connected transformers are used. Here one transformer is supplying power to the group of customers.

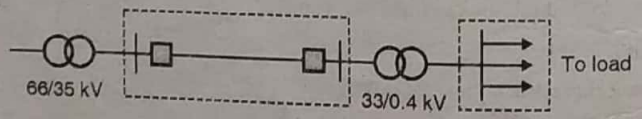

Fig. 2.2.4

- Secondary distribution system is having commonly used four types as below
- Individual transformer connected to only one consumer
  - One transformer having common secondary connected to group of consumers
  - Two or more number of transformers having common secondary connected to one feeder supplying power to group of consumers
  - Two or more number of transformers having common secondary connected to two or more primary feeders supplying power to group of consumers.

- Each of above types is used depending on the application and its suitability.
- Primary distribution system, secondary distribution system depending on the connection are mainly classified as :

(1) Radial distribution system
(2) Parallel or Loop distribution system
(3) Ring or Network system

(1) Radial distribution system

- A simple radial distribution is shown in Figure. It is most commonly used. Radial distribution system are simple to construct and less expensive.
- It receives power at utilization voltage level.
- In a radial distribution system, a single feeder is assigned a load to be supplied.
- In a radial distribution system, laterals are also used to supply a power. These laterals are connected to the radial feeder.
- In case of fault it is very difficult to maintain the supply, causing loss of power supply to the customers.

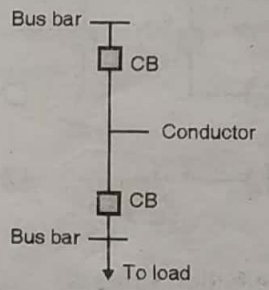

Fig. 2.2.5

(2) Parallel or Loop distribution system

- In parallel distribution system, another conductor is provided in parallel to existing feeder. Simple parallel distribution system is shown in fig. 2.2.6.
- Here as one feeder is running in parallel with existing one who supplies power to the area provides more reliable power in case of fault on any one of the feeder. Here load of faulty feeder is transfer to the other feeder.
- When a transformer get overloaded or a fault occurs on the transformer, fuse of the transformer primary gets open and disconnects the transformer from the loop with other secondary units thus substation loads are unaffected.
- Here two more transformers are connected in the loop to increases the reliability and efficiency of the power supply. It is costly system due to presence of parallel conductor with existing conductor.

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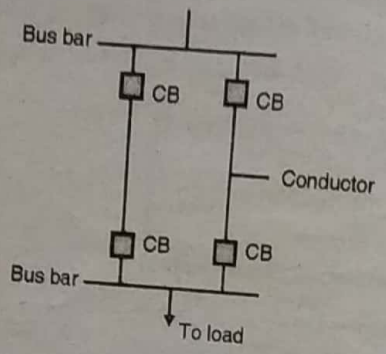

Fig. 2.2.6

(3) Ring or Network System

Here all conductors lines are connected to each other with the help of bus bars forming a close loop. In case of fault, load is transfer from one distribution line to other distribution line. Due to such arrangements interruption duration decreases. It provides better voltage regulation with fewer losses in feeder.

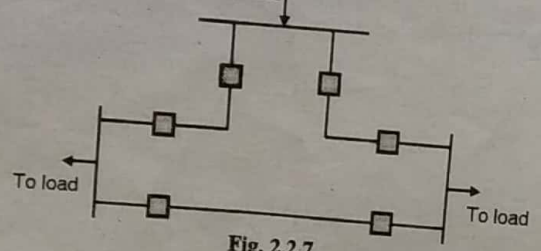

Fig. 2.2.7

2.2.3 Distribution System Selection Criteria

(1) Voltage level : For power transfer higher voltage level (like 33/22/11 kV) underground system is useful.

(2) Usage Area : Usage area is sub divided as rural or urban area. In urban area mostly underground distribution systems are used.

(3) Cost : Underground system requires larger cost so they are preferred in highly populated urban areas.

Cost includes :

(1) Depression cost (2) Operating cost

(3) Overhead cost (4) Electrical loss cost

(4) *Reliability :* *As urban customers are ready to pay the cost of electricity so they demand highest amount of reliability of supply. In this case we are preferring underground distribution system. To improve reliability network systems are considered mainly.*

(5) *Safety :* *From safety point of view underground distribution systems are more preferred as compare to the overhead distribution system.*

(6) Flexibility : Overhead distribution system is more flexible as compare to underground distribution system.

Electrical power distribution systems are either three wire or four wire systems. In case of 4 wire system, 3 wires are phases while 1 wire is for neutral.

Electrical load size of the load determines the capacity of substation load estimation is very important for busbars designing and sizing of equipments e.g. Transformer etc.

Before calculating load size we have to divide the load into two types.

(1) Non industrial load
(2) Industrial load

(1) Non industrial load

This further divided as

(a) Lighting load : It involves both indoor and outdoor lighting.

(b) Small electrical appliance load. If includes air conditioning, TV, fridge, washing machines, geysers, mixers, fans etc.

(c) Water pumping load : It comes in picture only when rural areas are considered mostly.

(d) Dynamic loads : It includes lifts and elevators etc.

(2) Industrial loads : It is further subdivided into

(a) Heavy loads

(b) Medium loads

(c) Light loads

Loads are defined interns of w/m^2. Lighting loads are ranges from 2 to 50 $w\backslash m^2$. Small electrical appliances loads vary from 40 to 120 w/m^2. In case of small electrical appliances, air conditioning load occupies major consumption. Air conditioning load involves works department stores, shops, restaurants etc.

2.3 Temporary and Permanent Power Supply

It is very important to consider power supply in distribution system, failure to have power supply caves unable went to detect faults circuit breakers unable to trip in case of faults, unoperation of SCADA and automation systems. It is divided into two basic types.

(1) Temporary power supply

It consists of battery, battery charger with switching and protective devices. Sometimes these batteries are also used to supply intermittent and momentary loads like trip coils, dc motors etc.

There are few risks associated with temporary power supply and they are.

(a) Failure to supply trip current

(b) Short circuits of battery leads

(c) Sudden appearance of surge

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(d) Large maintenance cost if required

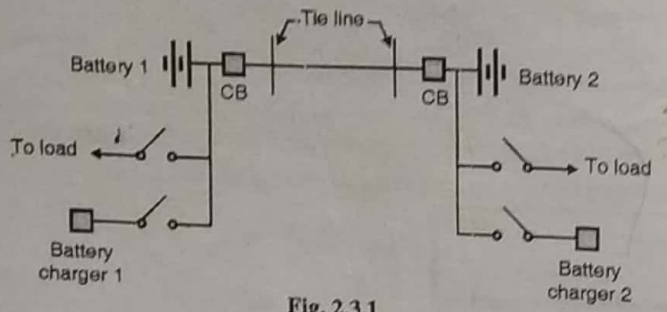

Fig. 2.3.1

(2) Permanent power supply

They are used to supply power to consumers with self controlled reclosures, power relays etc.

(1) **Protective Relays and Reclosures :** They are used to interrupt the fault by disconnecting the equipments. These are can be outdoor indoor also.

(2) **Grounding :** Here equipments are connected to earth with the help of wire. It used to transfer fault currents to ground to protect substation equipments. Grounding can be solidly grounded, undergrounded arid resistance grounded. They reduce the possibility of electric shocks to operating personnel.

2.4 Diversity Factor

It the ratio of sum of individual maximum demands to the maximum demand on power station. Maximum demand on power station is always lower than that of sum of individual maximum demand as maximum demand of each consumer cannot occur at the same time. So diversity factor is always larger than 1. Larger the diversity factor lower the cost of power generation.

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand on power station}}$$

2.5 Demand Factor (DF)

- It is the ratio of maximum demand to the total connected load

$$\text{Demand Factor} = \frac{\text{Maximum demand}}{\text{connected load}}$$

- Demand factor varies from type of loads to the types of consumers. Demand factor is always less than one. How demand factor indicates that we require less system capacity to serve connected load. Table describes the general demand factors associated with the type of loads.

Type of load	Demand factor
Residential House	0.8 – 0.95
Cinemas	0.75 - 0.95
Shops	0.6

Type of load	Demand factor
Restaurants, Theatres	0.65 - 0.85
Hospitals	
Kitchen	0.65
Lifts	0.9
Laundry	0.7
Medical Equipment's	0.5
Industry	
Lighting	0.9
Equipment's	0.5
Paper Mills, Rubber Mills, Refineries - having semi continuous operations	0.65
Textile Mills and Chemical Mills - having continuous operations	0.8
Welding	0.6

2.6 Load Factor (LF)

- It is the ratio of average load to the maximum demand

$$\text{Load Factor} = \frac{\text{Average load}}{\text{maximum demand}}$$

- Load factor is always greater than 1. Load factor can be a monthly, yearly or daily also. Cost per unit generated will be lesser if load factor is high.
- Higher load factor means lower value of maximum demand i.e. variation in load demand is less. Load factor can also be calculated as

$$\text{Load factor} = \frac{\text{kWh}}{\text{kW} \times \text{Days} \times 24}$$

kWh is the actual kill watt hours used

kW is the peak kilowatt demand

Day is the billing period

- We can improve load factor by reducing load demand which can be done by segregating loads over different times or demand side management. High load factor indicates the most economic fuel consumption.

2.7 Substation Equipment Option

- Distribution substations voltage level varies from 4 to 33k. it deriver power directly to the industrial commercial and residential consumers.
- Voltage level at which power delivered to the industrial, commercial and residential consumer usually from 230v to 400v.

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2.7.1 Components of Distribution Substation

Following are the main electrical components of distribution substation

(1) Supply Line

Secondary transmission system is connected to the distribution substation with minimum one line. This supply line may be overhead line (for rural areas) or underground time / cable (for urban areas). Isolators are used to isolate the supply line for maintenance work.

(2) Transformers

Transformers of distribution substations are 3-phase in nature sometimes banks of 1-phase transformer are also used. These transformers are step down in nature. Voltage rating of transformers varies from 33/22/11kV. Power rating varies from 5 to 50 MVA. Voltage regulation varies from 5 to 10%. Transformers are classified depending on following factors.

(1) Insulation

Transformers are having liquid insulation type or dry type. In liquid insulation transformer mineral oil and non flammable liquids are used. Dry type transformer are gas types.

(2) Voltage rating

It depends in the transmission and distribution substations voltage level requirement to which it is going to be connected.

(3) Winding connections

There two basic types of winding connection

(1) Delta connection

(2) Star connection

Basically distribution transformers are delta connected winding on high voltage side while star connection on low voltage side. Delta connection isolates two system with respect to some harmonics (specifically third harmonics) also star connection allows a neutral point for ground connection.

(4) Cooling

Transformers are natural cables or force cooled transformer which depends on the voltage rating of transformers. In case of distribution transformer it is always natural called transformer.

(5) Power rating

It is given in terms of kilowatt amperes (KVA) on mega volt amperes (MVA). Distribution transformer are KVA transformer rating ranges from 5 KVA to 20 MVA.

(3) Busbar

- Busbars are used to channelized currents to various circuits. Copper or Aluminium material are used to manufacture busbars.
- Size of busbar depends upon rated current, system voltage, flexibility, reliability of supply and cost.
- While designing busbar there should be a provision for future extension.

- Its design should be simple also maintains should be carried without interruption of power supply and any danger to the operating personnel.
- Mechanical characteristics of busbar should be good. It should not get break or damage due to variation in load demand.
- Busbars are used both on high voltage as well as low voltage side to connect electrical circuits or networks. Busbars are of two types
  1. Strain type and
  2. Rigid Type.
- Sometimes bus bars classification also taken as
  - Outdoor rigid bus-bars
  - Outdoor flexible ACSR or Al alloy bus-bars
  - Indoor bus bars

(4) Feeders

- Feeders are connected to the substations through busbars. Conductors sizes of feeders are depend on voltage level utilized to transfer power.
- Basically Aluminium Conductor Steel Reinforced (ACSR) are used in India as a feeder material. In European countries all aluminium alloy conductor (AAAC) are used to manufacture feeder.

(5) Switching equipments

Switching equipments are used to connect or disconnect the equipments of the power system to each other. Switching equipments mainly consists of circuit breakers, fuses, switches etc.

(a) Circuit breaker

Circuit breakers are used to open or close electrical circuit during normal and fault operation either manually or automatically. Operation of circuit breaker is set at predefined overload current magnitude. There circuit breakers are operated automatically or manually. Circuit breakers are single or double or triple or four pole operating at indoor as well as outdoor condition also.

Classification of Circuit Breakers

Circuit breakers are classified depending on the basis of medium used for arc extinction.

Accordingly they are classified as

- Air-blast circuit breaker
- Vacuum circuit breakers
- Oil circuit-breaker
- Sulphur hexafluoride circuit breakers

Circuit breakers are having various voltage range depending upon system requirement, and may be single, double, triple, or four-pole, and available in indoor or outdoor option also. Sulfur hexafluoride (SF_6) gas-insulated circuit breakers are commonly used for medium and high voltages ranges like gas-insulated substations.

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When a current is interrupted, an arc is produced which must be contained, cooled, and extinguished in a safer way. Circuit breakers can use vacuum, air, insulating gas, or oil as arc quenching medium. Different methods are used to interrupt and extinguish the arc, including:

- Lengthening of the arc
- Intensive cooling
- Formation of sub arcs
- Connecting capacitors in parallel with the opening contacts
- Zero point quenching - in this method contacts are open at the zero current time crossing of the AC waveform so that no-load current at the time of opening.

(b) Fuses

Fuses are over current protection device fuses classified as :

(1) Rewire able or kit-kat fuse
(2) Glass fuse
(3) HRC fuse

(1) Rewire able or kit-kat fuse

- As its name suggest it is rewire able type, here when current exceed the defined magnitude there will be a voltage drop causing increase in temperature which leads to the hefting of fuse wire and electrical circuit is isolated from supply lines.
- Here nickname, constantan, copper, aluminium are used as fuse wire material. Generally porcelin is used as a insulating material.

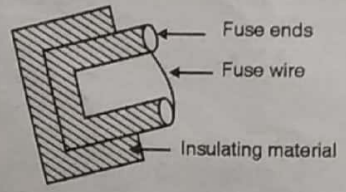

Fig. 2.7.1

(2) Glass fuse

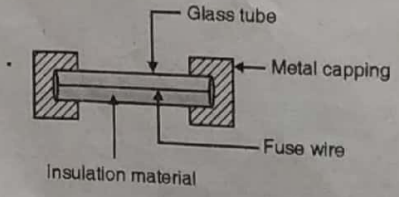

Fig. 2.7.2

- Glass fuse is shown in figure. It consists of glass tube with metal capping at its both ends. Glass tube carries fuse element with insulating material.
- Here nichrome or constantan are mainly used as a fuse element while insulating material is either vacuum or gas.

(3) HRC fuse

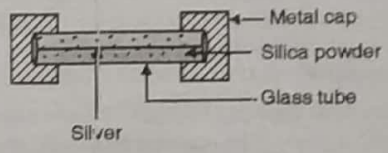

Fig. 2.7.3

- HRC stands for high rupturing capacity fuse. It is basically used in commercial and industrial consumers.
- Figure shows the HRC fuse having glass tube glass tube consist of fuse wire with insulting material. Here silver is use as a fuse wire while silica power as a insulating material. Glass tube carries metal caps at its both ends.
- Due to use of silver as fuse element cost of HRC fuse is large. When high current parses through the HRC fuse, silver wire get melted. This melted part is absorbed by silica powder.

(c) Switches

- They are also used for isolation of electrical circuit during overload current flow.
- These isolation switches sometime also used to carry out maintenance procedure on equipments.

(d) Isolators

They are used isolated the equipment or electric network to carryout maintenance. It is classified as.

- Vertical break type
- Horizontal break type
- Pantograph type

(6) Insulators

Insulator provides insulation to line conductor from the ground. Insulators are mainly made up of porcelain or glass.

Required properties of insulators are

(1) It should provide high resistance to any leakage current.
(2) It should have high mechanical strength to support conductors.
(3) It should have high dielectric strength.

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Type of insulators

(1) Pin type (2) Suspension type (3) Shake type (4) Strain type

(7) Relays

- It is a device which detects the fault and initiates the operation of the circuit breaker to isolate the fault or defective component from the other parts of the electrical system. It constantly measures the electrical quantities like voltage, current etc. which are going to be change under normal and fault condition.
- When it detects the fault the relay operates so as to close the trip circuit of the circuit breaker. Trip circuit is going to be operated by a direct voltage. The speed of operation of relay should be do such that fault is eliminated before it can cause any damage to the electrical component or electrical system.
- Classification of Relay
- It is classified as

(a) Electromagnetic attraction type :

It works on the principle where the relay armature is attracted by an electromagnet.

(b) Electromagnetic induction type :

It works on mutual induction principle where two different fluxes having different phase angles interact with each other with same or different amplitude and nearly equal frequencies. Here net torque developed operates to rotate the induction disc.

The most commonly used functional relays are

- Distance or Impedance relay
- Translay scheme
- Differential relay
- Induction type over-current relay
- Induction type reverse power relay

(8) Lightning Arrester

- Lighting is nothing but a electric discharge between the clouds, between clouds and earth, between the charge points of the same cloud. Lightning can strike the power system directly.
- Lighting arrestors are used to overcome the lighting by offering low resistance path to the surges.
- They are classified as
  - Rod gap arrester
  - Horn gap arrester
  - Multi-gap arrester

(9) Other Equipments

Surge arresters

It palced between phase conductor and ground. Main use is to discharge over voltage surges to earth.

Current Transformer (C.T)

C.T. location is decided by protective zone measurement requirments. It steps down the current for measurements protection and control. In CT, primary winding has one or lesser number of turns while it is connected in series with the line carrying the current which is to be measure. The secondary winding has large number of turns of fine wire. It is used for the measuring and protection purpose.

Potential transformer (P.T)

It placed on feeder side of circuit breaker. It steps down the voltages for measurements, protection and control. In PT, primary winding has larger number of turns while it is connected in parallel with the line whos voltage which is to be measured. The secondary winding has lesser number of turns of fine wire. They are shell type transformer. Secondary winding is completely insulated from high voltage primary winding.

Shunt reactors

It is connected to distribution lines. During low load period it controls the voltage.

Shunt-capacitors

They are placed at receiving stations and distribution sub-stations. They improve power factor by compensating reactive power (lagging).

Series capacitors

They are placed at sending end and or receiving end of line. They improves power transfer capacity of distribution system in case of long line.

Series reactors

It is placed at sutable locations to reduce fault levels. They limit the short circuit current to limit current surges linked with variable or fluctuating loads.

Air Break switch

This is an airbreak switch for isolation.

Drop-out fuse

It is connected to the primary of distribution transformer in the incoming line. In case of fault the drop-out fuse melts and the line is tripped while drop-out fuse remain hagging.

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Cross arms

These are required for supports to the strain insulator to keep spacing between dictribution conductors.

Anti-climbing device

For pole mounted substation, this arrangement is for safety.

Sub-station earthing

Substation earthing system is needed for providing the protection to peoples living and working in the nearby facilities and the equipments to maintain proper working of electrical system. The main aim of sub-station earthing is to provide the uniform potential around substation in actual case near to zero.

(i) All parts of equipment connected to the earthing system should be at the ground potential.

(ii) Operators and attendants should be at ground potential at all the times.

- The earthing system gives a needed less resistance return path for earth fault currents which protects both personnel and equipment. It indirectly avoids the presence of dangerous high level voltage across equipment's and working personnel.
- Earthing prevents dangerous rise in ground potentials i.e. touch and step voltages
- Earthing system also provides a low resistance path for voltage transients due to lightning and surges / overvoltages
- Earthing system provides a ground or reference potential for electronic circuits which is necessary to reduce electrical noise for electronic, instrumentation and communication systems

Above calculation are based on the guidelines given by the IEEE Std 80 (2000), "Guide for safety in AC substation grounding".

Types of Earthing

The earthing is classified as

1. **System Earthing**

   In this case the protection of electrical equipment is done by stabilizing the voltage w.r.t. the ground e.g. part of plant in an operating system like low voltage neutral connection of a Power Transformer winding is connected to the earth.

2. **Equipment Earthing** (Safety grounding)

   In this case the protection of working personnel from electric shock is considered mainly by having potential of noncurrent carrying equipment at or near to the ground potential. Connecting frames or bodies of equipment e.g. motor body, Transformer tank, Switch gear box, etc. are connected to the earth.

The system earthing and equipment earthing are connected to each other and due to this fault current flowing through system to ground increases the potential of the safety ground but separating the two earthing systems have many disadvantages e.g. higher short circuit current, small and low value current flowing through relays and length of ground wire increases.

Types of Earth Electrode

1. Rod electrode.
2. Pipe electrode.
3. Plate electrode.

The earth resistance should be as low as possible and should not increase beyond following limits. Table describes the earth resistance values as

Particulars	Permissible values
Power Stations	0.5 Ohms
EHT Substations	1.0 Ohms
33KV Stations	2.0 Ohms
D/T centers	5.0 Ohms
Tower foot resistance	10.0 Ohms

Depending on soil resistivity, the earth conductor should be buried at the following depths.

Soil Resistivity in ohms/meter	Economical depth of Burial in meters
50 – 100	0.5
100 – 400	1.0
400 – 1000	1.5

For keeping earth resistance as low as possible following points should be kept in mind

Remove oxidation rust on joints and joints should be tight

Place sufficient water in earth electrode

Used larger size earth electrode

Electrodes should be connected in parallel

Earth pit should be of more depth & width

Plate Earths

The size of plate earths are taken as

Power Stations & EHV Station - Main - 100 x 16 mm
Auxiliary - 50 x 8 mm
Small Stations - 75 x 8 mm

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Earthing System in a sub-station consists of Earth Mat or Grid, Earth Electrode, Earthing Conductor and Earth Connectors.

Earth Mat or Grid

- Main need of earthing is to get a low earth resistance. Substation have many earthings by having individual Electrodes (may have fairly high resistance). But if these individual electrodes are joined together inside the soil, it increases the contact area with the soil and develops huge number of parallel paths. Hence the value of the earth resistance in the connected mode has lower resistance than the individual one.
- This inter connection is done by connection of flat or rod conductor which is called as earth mat or grid. It maintain all substation equipment as nearly as ground potential as possible. To get this we need proper earthing system so the earth mat should be designed in proper manner by having safe value limit of step potential, touch potential and transfer potential. Figure shows general diagram of earth mat.

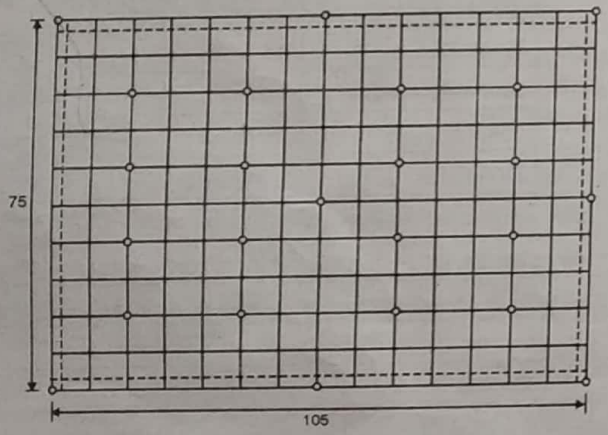

Fig. 2.7.4

The factors are affecting the Earth Mat design

- Value of Fault Current
- Duration of Fault
- Soil Resistivity
- Surface Material resistivity
- Shock Duration
- Material of Earth Mat Conductor
- Earthing Mat size and shape

Design parameters required are

- Size and material of Earth Grid Conductor
- Step and Touch Potential
- Mesh Potential
- Grid configuration for Safe Operation
- Number of Electrodes required

2.8 Layout of Distribution Substations

- **Floor Mounted Outdoor Distribution Substation**

Here step-down transformer is used having oil-immeresed having cooling tubes. The incoming power line can be underground cable but the outgoing line is overhead line with line insulators, lighting arrestors, switching devices etc. It is used in co-operative housing societies.

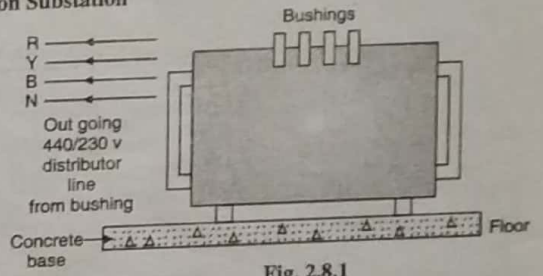

Fig. 2.8.1

- **Pole Mounted Distribution Substation**

It is used in locations where area availble is less with large populations where no obstacles to incoming and outgoing lines. Figure shows general diagram of pole mounted distribution substation.

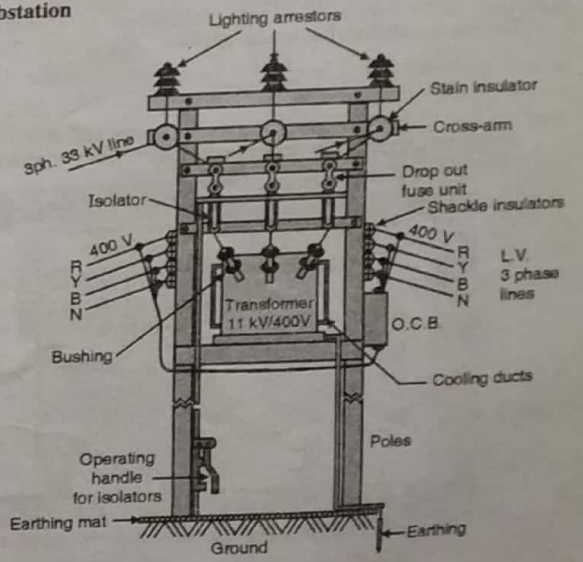

Fig. 2.8.2

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- **Indoor Distribution Substation**

Indoor substation are used in areas where atmospheric conditions are rainy or humid in nature. Entire substation is completely covered by metal walls or concrete buildings walls. Fig. 2.8.3 shows general single line diagram of indoor distribution substation.

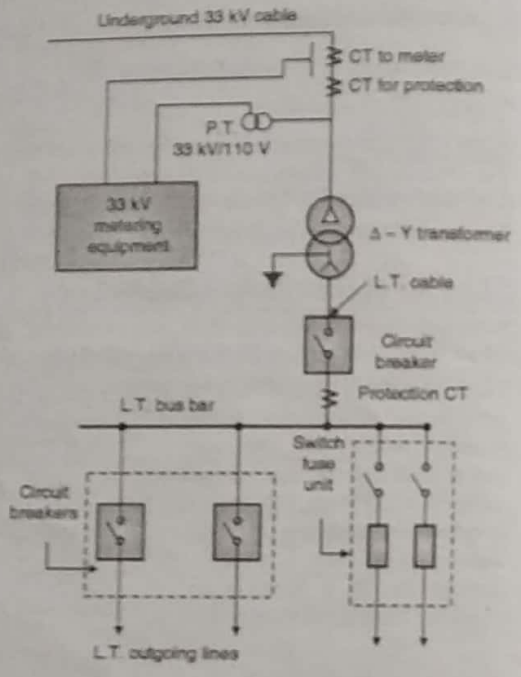

Fig. 2.8.3

- **Underground Distribution Substation**

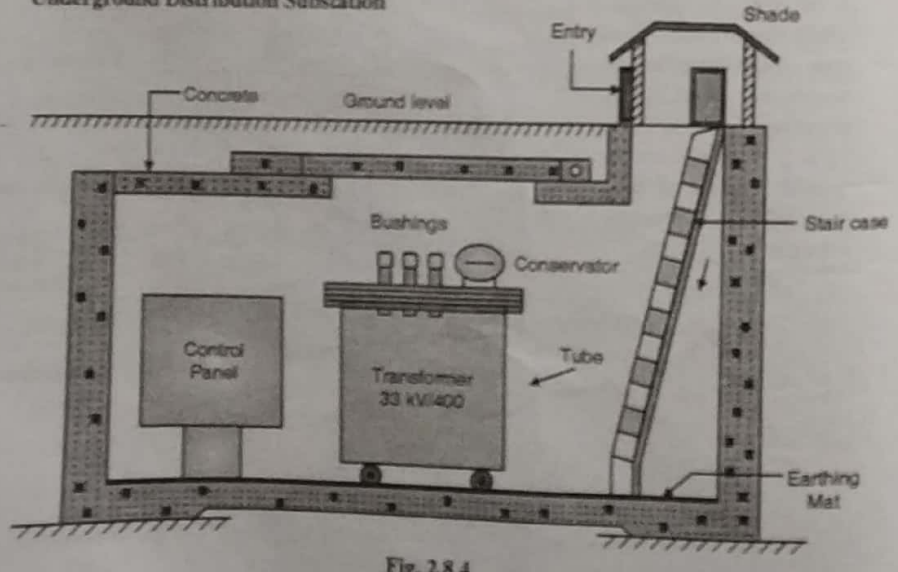

Fig. 2.8.4

It is shown in the fig 2.8.4. The size of this substation type is as minimum as possible with emergency stand by lightsand protection against fire. Fig. 2.8.4 shows general diagram of underground distribution substation.

Following things are required in underground sub-station are

- Immergency light, fire protection, fire alarm for safety.
- Adequate and proper ventilation.
- Proper access to persons and equipment-handlers

2.9 Load Allocation Method used for Distribution Transformer

- Four different methods are commonly used for allocating load to the distribution transformers and they are
  - Application of diversity factors depending of load
  - Load survey method
  - Transformer load management based on demand side management
  - Metered feeder maximum demand method
- In case of application of diversity factor method load is assigned to the larger capacity transformer to the load area having larger diversity factor. Diversity factor is the ratio of sum of individual maximum load to the maximum demand on the power station. It is always greater than one.
- In case of load survey method load is assigned to a transformer by maintaining equal sharing of load among each phase of distribution transformer.
- In case of transformer load management method load is given or distributed among transformer based on demand side management issues.
- In case metered feeder maximum demand method load is assigned to transformer depending upon the maximum power carrying capability.
- For analysis purpose if total feeder is need to be analysed allocating load based upon the kVA ratings of the transformers is mostly used.

2.10 Design Considerations in Transformer Selection

In case of transformer selections following design consideration are used.

(1)	Power rating	(2)	Transformer core
(3)	Insulation Coordination	(4)	Voltage rating
(5)	Short circuit impedance	(6)	Loss calculation
(7)	Temperature rise limit	(8)	Cooling
(9)	Over load capacity	(10)	Sound level
(11)	Tap changer	(12)	Size of transformer
(13)	Types of loads		

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(1) Power rating

It is calculated by following formulas

$$P = \sqrt{3} \times V \times I$$

Where,

V – Rated line voltage

P – Rated line current

It is given in MVA. Depending on the MVA rating cooling arrangements are used.

- Oil cooled
- Air cooled
- Air forced cooled

(2) Transformer core

Transformer cores can be 3 or 2 legs even sometimes 4 to 5 legs are also used. Rectangular core requires more length of copper for same number of turns as compared to circular core. Therefore circular cores are preferred.

(3) Insulation co-ordination

Here we are considering

(1) Basic insulation level (BIL)

(2) Switching insulation level (SIL)

(3) Induced voltage (ac)

(4) Applied voltage (ac)

- BIL is used for designing bushings lead structures, winding clearances, neutral point insulation etc.
- SIL is used for calculation of external clearances, lend clearances, phase to phase stresses.
- Induced voltage is used to calculate internal winding stresses.
- Applied voltage is used to calculate stresses to ground.

(4) Voltage rating

(a) High voltage

It is used for selection of bushings surge arrestors, insulating structures. Impulse voltage distribution used for selection of winding type, main gaps, type of conductors.

(b) Low voltage

Low voltage generates the highest currents in transformer which affect the selection of bushing and lead structures.

(5) Short circuit impedance

Short circuit impedance limits the short circuit currents and resulting forces produced. It determines the regulation under load conditions.

Low value of short circuit impedance in design results in

- High leakage flux causing high eddy current losses in windings and cores.
- High temperature rise
- High voltage regulation

(6) Loss calculation

Losses are divided into two types

- No load loss and

  It consists of hysteresis losses and eddy current losses occurs in transformer cores

- Load loss

  It consists of ohmic losses and eddy current losses. As temperature increases the ohmic losses are also increases as resistance depends on temperature.

These losses decide the efficiency level of transformer.

No load losses are depends on

- Voltage level
- Frequency
- Core material

Load losses are depends on

- Current level
- Core material

(7) Temperature rise limits

In designing and selection of transformer temperature rise plays vital role. We consider temperature rise in.

- Windings of transformer
- Oil if oil cooled transformed used
- Metal parts

Following table gives the allowable value of temperature rise

Part	Allowable temperature rise
Winding	Avg – 55 to 65°c Hot spot –65 to 80°c
Oil	55 to 65 °c
Metal parts	Up to 100°c

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(8) Cooling

In transformer both no load and load losses are converted into heat which causes increase in temperature of active parts (core and winding) out constructional parts (oil tank and clanups etc) this heat read to be dissipated properly for good heat read to tbe dissipated properly for good working of transformer.

For cooling of transformer one can use

- Radiators or coolers
- Forced air flow
- Forced oil flow
- Water cooling
- Increase structure of tank like cooling ducts.

Cooling methods are divided into two parts both internal (first part) and external (second part) having medium and mechanism like

- ONAN – Oil Natural, Air Natural
- ONAF – Oil Natural, Air Forced
- ODAF – Oil Directed, Air Forced
- OFAN – Oil Forced, Air Natural
- OFAF – Oil Forced, Air Forced
- ODWF – Oil Directed, Water Forced
- OFWF – Oil Forced, Water Forced

(9) Overload capacity

Overload capacity of transformer depends on oil temperature and hot spot temperature. So it indirectly depends on the cooling method used in transformer. Maximum allowable hot spot temperature is 120°C.

(10) Sound level

Sound produced in transformer is because of magneto-striction in core caused by changing magnetic flux with fundamental frequency.

Sound level in transformer depends on

- Core material
- Magnetic flux density in core
- Core weight
- Tank design and
- Cooling system

(11) Tap changers

Tap changers are divided into two types

- On-load Tap Changer
- Off-load Tap Changer

On-load tap changers are designed to change the voltage under load without de-energizing the unit. These tap changers are built as

- Resistive type with current limiting resistors
- Reactive type with preventive auto transformer

(12) Size of the transformer

Size of the transformer increases with output of the transformer.

(13) Electrical load

Electrical Load Classification and Types

The electrical loads can be classified into various categories according to various factors as follows:

1. **According to Load Nature-1**
   - Resistive Electrical Loads.
   - Capacitive Electrical Loads.
   - Inductive Electrical Loads.
   - Combination Electrical Loads.
2. **According to Load Nature-2**
   - Linear Electrical Load.
   - None-Linear Electrical Load.
3. **According to Load Function**
   - Lighting Load.
   - Receptacles / General / Small Appliances Load.
   - Power Loads.
4. **According to Load Consumer Category**
   - Residential Electrical Loads (Dwelling Loads).
   - Commercial Electrical Loads.
   - Industrial Electrical Loads.
   - Municipal / Governmental Electrical Loads (Street Lighting, Power Required For Water Supply and Drainage Purposes, Irrigation Loads and Traction Loads).
5. **According to Load Grouping**
   - Individual Loads (Single Load).
   - Load Centers (Area Loads).

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6. **According to Load Planning**
   - Existing Electrical Loads.
   - Future Electrical Loads (Electrical Loads Growth).
   - New Electrical Loads (Additional Electrical Loads).
7. **According to Load Operation Time**
   - Continuous Electrical Loads.
   - Non-continuous Electrical Loads.
   - Duty, Intermittent Electrical Loads.
   - Duty, Periodic Electrical Loads.
   - Duty, Short-Time Electrical Loads.
   - Duty, Varying Electrical Loads.
8. **According to Load Importance**
   - Vital Electrical Loads (Life Safety Electrical Loads).
   - Essential Electrical Loads (Emergency Electrical Loads).
   - Non-Essential Electrical Loads (Normal Electrical Loads).
9. **According to Load /phase distribution**
   - Balanced Electrical Loads.
   - Non-Balanced Electrical Loads.
   - Neutral load.
   - Line to neutral load.
10. **According to number of Electrical Loads phases**
    - Single phase Electrical Loads.
    - Three phase Electrical Loads.
11. **According to actual Electrical Loads value**
    - Nameplate load.
    - Full load.
    - Percent of full load.
    - No load (Open Circuit).
12. **According to Electrical Loads unit**
    - Electrical Loads in KVA.
    - Electrical Loads in KW.
    - Electrical Loads in HP.
13. **According to Electrical Loads diversity (simultaneous and non- simultaneous operation)**
    - *Connected Load.*
    - Demand Load.

14. **According To Unity Electrical Load Units**
    - Unity Electrical Load in VA/M2.
    - Unity Electrical Load in VA/Ft2.
    - Unity Electrical Load in VA/Linear Foot.
15. **According To Electrical Loads Operation Coincidence**
    - Non-Coincident Electrical Loads.
    - Coincident Electrical Loads.
16. **According To Electrical Loads Usage Method**
    - Fixed In Place Loads.
    - Portable Loads.
17. **According To Method of Load Reduction / Control**
    - Dimmed Electrical Load.
    - Shed Electrical Load.
    - Shifted Electrical Load.

2.11 SLD Indicating Different Type of Metering, Protections

MU - May 2016

(a) Rating of transformer

Case (i)

$$\text{Maximum demand (MD)} = \frac{\text{Power}}{D_F} = \frac{600}{0.8} = 750$$

$$\text{Maximum kVA} = \frac{\text{Maximum Demand}}{\text{pf}} = \frac{750}{0.85} = 882.35$$

$$\text{Distribution transformer rating } (DTR_1) = \frac{\text{Maximum KVA}}{\eta \times Lf} = \frac{882.35}{0.85 \times 0.8} = 1297.6 \text{ kVA}$$

Case (ii)

$$MD = \frac{200}{0.8} = 250, \quad \text{Maximum kVA} = \frac{250}{0.8} = 312.5$$

$$DTR_2 = \frac{312.5}{0.7 \times 0.7} = 637.75 \text{ kVA}$$

Case (iii)

$$MD = \frac{300}{0.7} = 428.57, \quad \text{Maximum kVA} = \frac{428.57}{0.7} = 612.24$$

$$DTR_3 = \frac{612.24}{0.8 \times 0.8} = 956.63 \text{ kVA}$$

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Case (iv)

$$MD = \frac{200}{0.5} = 400, \quad \text{Maximum kVA} = \frac{400}{0.7} = 571.43$$

$$DTR_4 = \frac{571.43}{0.7 \times 0.7} = 1166.18 \text{ kVA}$$

Total distribution transformer rating = $DTR_1 + DTR_2 + DTR_3 + DTR_4$

= 1297.6 + 637.75 + 956.63 + 1166.18 = 4058.16 kVA ≈ 4060 ≈ kVA ≈ ¼ 100 kVA

So the rating of transformer is 4100 kVA

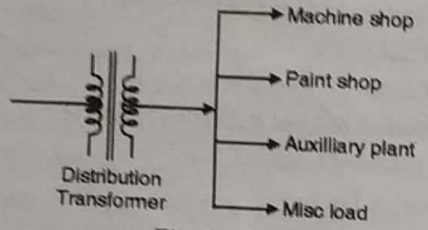

Fig. 2.11.1

(b) SLD indicating different type of metering and protections

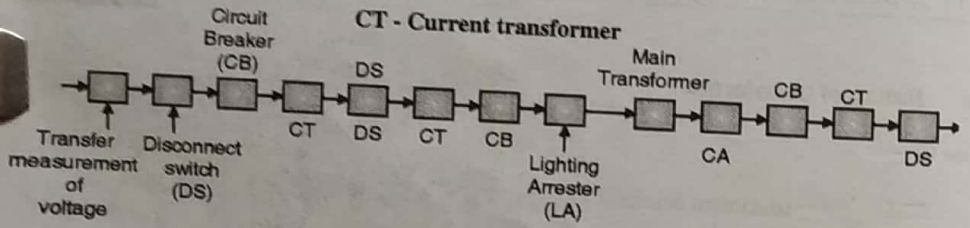

Fig. 2.11.2

2.12 Transformer Sizing and Specification

For proper selection of transformer we have do following steps

1. Calculate electrical load

For calculating electrical we to consider

- Voltage needed by electrical the load.
- Amperes or kVA capacity needed by the load.
- Frequency of power supply in Hz (cycles per second)
- Check whether the load is either single phase or three phase in nature

This information can be collected from equipment nameplates or instruction manuals or directly from manufacturer also.

2. Determine supply voltage

Here only two things are important

Voltage of supply (source)

Frequency in Hz (cycles per second)

We have to take care that the operating frequency of the supply and electrical load must be the same. Then select single phase or three phase transformer designed to operate at this frequency, having a primary voltage level equal to the supply voltage and a secondary is equal to the voltage needed by the load.

3. If the load nameplate describes a rating in kVA, a transformer can be chosen directly from the charts given by the IS or IEEE standards. Choose a transformer having primary and secondary voltages matching or just above the calculated value.

Select a transformer having standard kVA capacity equal to or greater than that of the load.

Use proper taps to reduce the line voltage variations.

When load ratings are given only in amperes, use following formulas to calculate proper kVA size for the required transformer.

kVA can be calculated if volts and amperes are known as

kVA = (Volts x Amps) / 1000

Amperes can be calculated if KVA and volts are known as

Amps = (kVA x 1000) / Volts

2.13 IS Standards Applicable in Above Design

- IEEE standards 80 (2000) describes the guide lines for the substation grounding.
- IEC 60947-2 is used for describing the circuit breaker standards for its selection regarding short circuit current rating.
- IEC 60076-5 describes the typical values of short circuit voltage of transformers.
- Standard ANSI C57.92 describes the overload capacity values for transformers.
- IEEE standards C57.12·00 -2010 describes the general requirements for liquid / oil filled distribution transformers
- IEEE standards C57.12·90-2010 provide standard test code for liquid/oil distribution transformer
- IEEE standard 141-1993 prescribes the nominal system voltage level for distribution system.
- IEEE and C57.12·00-2000 describes the basic lighting impulse insulation level for oil transformers.
- IS 6600 - 1972 explains the loading level of oil immerged transformers.
- IS 13964-1994 describes the methods of measurement of transformer and reactor sound level.
- IS 2026-2010 guides the temperature rise of oil immersed transformer
- IS 2026-1977 is used for terminal working, tappings and connections.

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2.13.1 Solved Examples

Ex. 2.13.1 : Given a single-phase 230-volt load in a factory is rated at 100 kilowatts. The feeders (two hot lines) will be 300-foot lengths of RHW copper conductor. The maximum conductor voltage drop allowed is 3%. P = 10.4.
Find the feeder conductor size required.

Soln. :

Maximum voltage drop is

$$Vp = 0.03 \times 230 = 6.9 \text{ V}$$

Current drawn by the load is

$$I = \frac{\text{Power}}{\text{Voltage}} = \frac{100 \times 1000}{230} = 434.8 \text{ A}$$

Area of Conductor is

$$A = \frac{\rho \times I \times 2d}{V_D} = \frac{10.4 \times 434.8 \times 2 \times 300}{6.9} = \frac{2713152}{6.9} = 393210.4 \text{ cmil}$$

Ex. 2.13.2 : A generating station has a connected load of 60 MW and maximum demand of 30 MW. The units generated being 80×10^6 per annual Calculate demand factor and average demand.

Soln. :

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{connected load}}$$

$$\text{Demand factor} = \frac{30}{40} = 0.75$$

$$\text{Average demand} = \frac{\text{units generated / annual}}{\text{hours in a year}} = \frac{80 \times 10^6}{8760}$$

$$\text{Average demand} = 9132.42 \text{ W}$$

Ex. 2.13.3 : A generating station of 80 MW delivers 80 MW for 3 hours, 60 MW for 5 hours and shut down for rest of each day. It is also shut down for maintenance for 55 days each year. Calculate its energy supplied annually and % annual load factor.

Soln. :

Energy supplied for each working day $\Rightarrow$

$$= (80 \times 3) + (60 \times 5) = 540 \text{ MWh}$$

$$\text{Station operates for} = 365 - 55 = 310$$

$$\text{Energy supplied / year} = 540 \times 310 = 167{,}400 \text{ MWh}$$

$$\text{Annual load factor} = \frac{\text{MWh supplied / annum}}{\text{max demand in MW} \times \text{working Hours}} \times 100$$

$$= \frac{167400}{80 \times 310 \times 24} \times 100 = 28.125 \%$$

Ex. 2.13.4 : A generating station has connected load of 60 MW and a maximum demand of 45 MW. The units generated being 70×10^6 per annul Calculate

(1) Demand factor

(2) Load factor

Soln. :

$$\text{Demand factor} = \frac{\text{maximum demand}}{\text{connected load}} = \frac{45}{60} = 0.75$$

$$\text{Average demand} = \frac{\text{units generated / annual}}{\text{hours in year}} = \frac{70 \times 10^6}{8760} = 7990.867 \text{ kW}$$

$$\text{Load factor} = \frac{\text{average demand}}{\text{maximum demand}} = \frac{7990.9}{45 \times 10^6} = 0.178$$

Ex. 2.13.5 : A 300 MW power station delivers 300 MW for 3 hours, 150 MW for 6 hours and shut down for rest of each day. It is also shut down for maintenance for 60 days each year. Calculate its annual load factor.

Soln. :

$$\text{Energy supplied for each working day} = (300 \times 3) + (150 \times 6) = 1800 \text{ MWh}$$

$$\text{Station operates for} = 365 - 60 = 305 \text{ day in a year}$$

$$\text{Energy supplied / year} = \frac{1800}{305} = 5{,}49{,}000$$

$$\text{Annual load factor} = \frac{\text{MWh supplied per annual}}{\text{maximum demand in Mw} \times \text{working hours}}$$

$$= \frac{549000}{300 \times 305 \times 24} \times 100 = 25\%$$

Ex. 2.13.6 : A power supply is having the following loads.

Type of load	Maximum demand	Diversity	Demand factor
Residential	1200	1.4	0.8
Commercial	1800	1.2	0.9
Industrial	10000	1.3	1

If the overall system diversity factor is 2.Calculate

(1) Maximum demand and

(2) Connected load of each type.

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Soln. :

The sum of maximum demand of three loads is

$1200 + 1800 + 10000 = 13,000$

$$\text{Maximum demand on supply system} = \frac{\text{sum of individual maximum demand}}{\text{system diversity factor}} = \frac{13000}{2}$$

$$= 6,500 \text{ kW}$$

Sum of maximum demands of different domestic consumers = maximum demand × diversity factor

$$= 1200 \times 1.4 = 1680 \text{ kW}$$

$$\text{Connected residential load} = \frac{1680}{0.8} = 2100 \text{ kW}$$

$$\therefore \text{Connected commercial load} = \frac{1800 \times 1.2}{0.9} = 2400$$

$$\therefore \text{Connected industrial load} = \frac{1000 \times 1.3}{1} = 13000$$

Ex. 2.13.7 : A residential load of a locality is given below

Time (hrs)	0-5	5-6	6-9	9-18	18-21	21-24
Load (MW)	5	8	20	0	16	10

Draw the load curve and find out the load factor and energy consumed during 24 hrs.

Soln. :

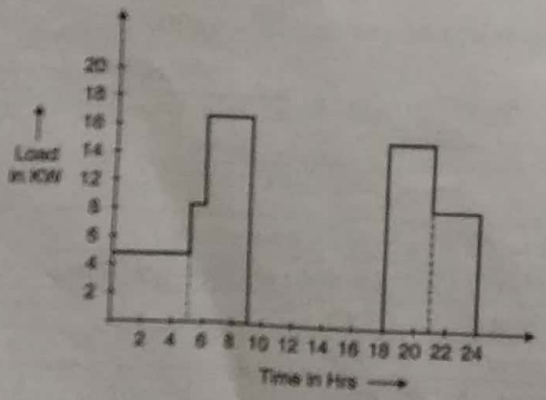

Fig. P. 2.13.7

Total energy consumed during 24 hours

$$= (5 \times 5) + (8 \times 1) + (20 \times 3) + (16 \times 3) + (10 \times 3)$$

$$= 25 + 8 + 60 + 48 + 30 = 171 \text{ kW hrs}$$

$$\text{Average load} = \frac{\text{energy consumed during 24 hrs}}{\text{hours of a day}}$$

$$= \frac{171}{24} = 7.125 \text{ kW}$$

$$\text{Load factor} = \frac{\text{average load}}{\text{maximum demand}} = \frac{7.125}{20} = 0.356$$

Ex. 2.13.8 : A solar power plant supply power to following loads of various consumer

Industrial consumer – 1000 kW

Commercial consumer – 1500 kW

Residential consumer – 500 kW

Muncipal consumer – 500 kW

If maximum demand on station is 3000 kW and number of kWh generated per year is 60×10^5. Calculate diversity factor and annual load factor.

Soln. :

$$\text{Diversity factor} = \frac{1000 + 1500 + 500 + 500}{3000}$$

$$= \frac{3500}{3000} = 1.167$$

$$\text{Average demand} = \frac{\text{yearly kWh generated}}{\text{Hrs in a year}}$$

$$= \frac{60 \times 10^5}{8760} = 684.93$$

$$\text{Load factor} = \frac{\text{average load}}{\text{maximum deamand}}$$

$$= \frac{684.93}{3000} = 0.228$$

Ex. 2.13.9 : A power station supplies the following loads to the consumers

Time (hrs)	0-6	6-10	10-12	12-16	16-20	20-22	22-24
Load (kMW)	30	60	25	45	90	10	20

Calculate load factor and draw load curve of the plant.

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Soln. :

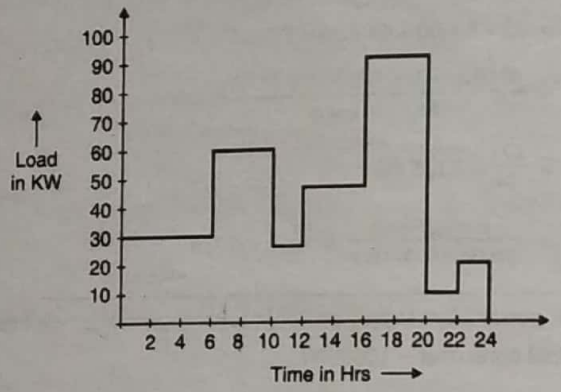

Fig. P. 2.13.9

$$\text{Energy generated} = (30 \times 6) + (60 \times 4) + (25 \times 2) + (45 \times 4) + (90 \times 4) + (10 \times 2) + (40 \times 2)$$

$$= 180 + 240 + 50 + 90 + 360 + 20 + 20 + 40 = 980$$

$$\text{Average load} = \frac{\text{Energy consumed during 24 hrs}}{\text{Hours of a day}} = \frac{980}{24} = 40.83$$

$$\text{Load factor} = \frac{\text{Average load}}{\text{Peak load}} = \frac{40.83}{90} = 0.454$$

Ex. 2.13.10 : The annual load duration curve of a certain power station can be considered as a straight line from 30 MW to 5 MW. To supply this load, three generator units are used, two rated are 15 MW each and one rated at 10 MW are installed calculate :

(1) Installed capacity (2) Plant factor

(3) Unit generated / annual (4) Load factor (5) Utilization factor

Soln. :

(1) Total installed capacity = 15 + 15 + 10 = 40 MW

(2) From load duration curve

$$\text{Average demand} = \frac{1}{2}[30 + 5] = 17.5 \text{ MW}$$

$$\text{Plant factor} = \frac{\text{Averge deamnd}}{\text{plant capacity}} = \frac{17.5}{40} = 0.4375 \text{ or } 43.75\%$$

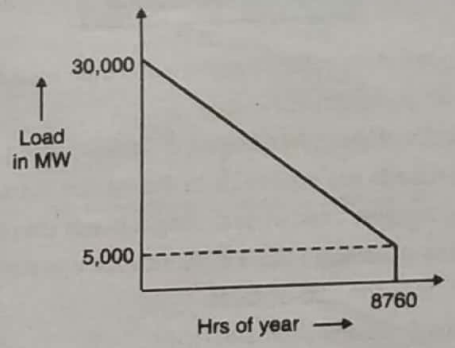

Fig. P. 2.13.10

(3) Units generated / annual = Area in kWh under load duration curve

$$= \frac{1}{2}[5000 + 30000] \times 8760$$

$$= 153.3 \times 10^6 \text{ kWh}$$

(4) Load factor $= \frac{17500}{30000} \times 100 = 58.33\ \%$

(5) Utilization factor $= \frac{\text{maximum demand}}{\text{plant capacity}} = \frac{30000}{40000} = 0.75$ or 75%

Ex. 2.13.11 : A generating station is to supply four regions of load whose peak loads are 15, 20, 30, 35. The diversity factor at the station is 2 and the average annual load factor is 80% calculate

(i) The maximum demand on the station

(ii) Annual energy supplied by the station

(iii) Installed capacity and the number of units.

Soln. :

$$\text{Maximum demand on station} = \frac{\text{sum of maximum demand of the area}}{\text{diversity factor}}$$

$$= \frac{15 + 20 + 30 + 35}{2} = \frac{100}{2} = 50 \text{ MW}$$

$$\text{Units generated / annual} = \text{maximum demand} \times \text{L.F.} \times \text{Hours in a year}$$

$$= 50 \times 10^3 \times 0.8 \times 8760 = 350.4 \times 10^6 \text{ kWh}$$

Assume installed capacity of station should be 20% of maximum demand.

$$\therefore \text{ Installed capacity} = 1.2 \times \text{maximum demand} = 1.2 \times 50 = 60 \text{ MW}$$

So unit size are 4 each having 15 MW capacity should be selected.

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Review Questions

Q. 1 What are different types of distribution system and their selection criteria

Q. 2 Explain major substation equipment's used

Q. 3 Explain design considerations in transformer selection, sizing and specifications

Q. 4 Explain which IS standards are applicable in distribution system design

Q. 5 Explain design consideration used in designing a power distribution system

Q. 6 Explain different types of earthing used in distribution systems.

Q. 7 Explain layouts of distribution sub-stations.

Q. 8 Describe electrical load classification and types

Q. 9 For proper selection of transformer we have do following steps

Q. 10 Describe commonly used IS standards applicable while designing power distribution System.

2.14 University Questions and Answers

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Q. 2(b) Discuss different types of distribution systems and their criteriaon.

(Ans. : Refer Section 2.2) **(10 Marks)**

. 3(a) The distribution transformer caters to the loads, the details of which are as follows:

	Type of load	Kw	η	pf	L_F	D_F
(i)	Machine shop	600	0.8	0.85	0.8	0.8
(ii)	Paint shop	200	0.7	0.8	0.7	0.8
(iii)	Auxiliary plant	300	0.8	0.7	0.8	0.7
(iv)	Misc. Load	200	0.7	0.7	0.7	0.5

(a) Calculate the rating of transformer.

(b) Draw SLD indicating different type of metering, protections etc.

(Ans. : Refer Section 2.11) **(10 Marks)**

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UNIT III

CHAPTER 3

Design of Switchgear Protection & Auxillary System

Syllabus

Selection of HT/LT switchgears, metering, switchboards and MCC, protection systems, coordination and discrimination. Cables selection and sizing, cable installation and management systems, busbars design; Basics of selection of emergency/backup supplies, UPS, DG Set, Batteries ; Preliminary design of interior lighting system. IS standards applicable in above designs

Objectives

After studying the chapter you will be able to

- Know the factors affecting selection of HT/LT switchgears
- Understand the factors affecting metering
- Understand the factors affecting switchboards
- Know the criterion affecting machine control centres (MCC)
- Know the benefits of better co-ordination and discrimination
- Understand the factors affecting Cables selection and sizing
- Understand the cable installation and management systems
- Know the factors affecting busbars design
- Understand the factors affecting selection of UPS
- Understand the criterion affecting selection of DG Set
- Know the factors affecting selection of Batteries
- Understand the factors affecting design of interior lighting system
- Know the IS standards applicable in above designs

1 Selection of HT/LT Switchgears

Use of electrical circuits of installations and the capabilities with limitations of switching devices collectively called as switchgear.

The use of switchgear are

(1) Electrical protection of equipment's against overload currents, short circuit current and insulation failure. Electrical protection is needed for animals and humans also.

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(2) Electrical isolation of sections.

Isolating device should have

- Poles of a circuit, including the neutral always remain in open position
- It should have locking system in open position to avoid unauthorized closure of isolating device
- It should follow all national or international standard related to clearance between contacts, creepage distances, overvoltage withstand capability, etc.

(3) Local and remote switching of devices for emergency stopping, carrying out mechanical maintenance, emergency switching.

- Switchgear items includes
  (1) Isolator or disconnector
  (2) Contactor
  (3) Fuse
  (4) Circuit breaker
  (5) Residual and over current circuit breaker
- Their selection criteria are
  (1) Performance
  (2) Compatibility with each other
  (3) Overload capacity
  (4) Short circuit current capacity
  (5) Emergency stopping characteristics
  (6) Load characteristics

3.2 Selection of Metering System

Metering systems used in distribution systems are portable or switchboard type. Now day electronic meters are commonly used. They provide two way communications between the meter and the central system. Due to use of electronic meter accuracy of measured quantity is assured. Selection of meters depends on the application for which it is used and they are

- Power factor measurement – here it directly measures the angle between voltage and current and displays it by taking "cos" of it.
- Revenue meter e.g. Wattmeter which measure power in kWh.
- Load demand measurement - Here meters are measuring maximum demand of the consumer in the specified periods. These periods may be day, week, month, year or any special day.
- Time of Day Metering - Here meters are used to measure the load demand on time basis for calculation of bills.
- Electronic metering - Here any form of theft of power is avoided.
- Frequency meter used for measurement of frequency.

Basic characteristic needed for metering system are

- High speed of response for change / variation of parameters.
- Maintenance cost of meters should be low
- Calibration required should be low
- Accuracy should be large
- Alarm facility in case of large variation in measured quantity.

- Short term disturbance detection facility (transients, interruption, sag, shell etc)
- Long term disturbance detection facility (over voltage, under voltage, power factor etc)
- Provide information about Temper alerts.
- Messaging facility.

3.3 Switch Board

- Switch board is a large single panel or assembly of panels. On which switches, over current and other protection devices, bures, and other instruments are mounted on the back or front side.
- It is mandatory to have a name plate on main switchboards. These nameplate must provide following information
  - Manufacturer's name and trade mark of the company
  - Serial number/drawing number of product
  - Insulation type
  - Insulation voltages
  - Relevant standard used during manufacturing and for application purpose
  - Earthing system used and its type
  - Rated current and whether it is ac / d.c,
  - Operating frequency in the case of a.c.
  - Rated voltages
  - Short-circuit withstand capacity
  - Degree of protection
  - Date of manufacture
  - Weight
- Switch boards may have one or more meters for display of various electrical quantities. Now days depending on the customer requirement switch boards have.
  - Lighting panel boards.
  - Distribution transformers.
  - Lighting control.
  - Motor starters.
  - Backup generators.
  - Power monitoring devices.
  - PLC
  - Automatic transfer switches.
  - Communication devices.

Selection criteria for switch boards are :

- Voltage stress withstands capability to detect insulation safety.
- Current carrying capability to check temperature increase.
- Availability of under voltage relay.
- Short circuit withstand capability to check arc risks.
- Protection against electric shock to assure working persons safety.
- Protection against fire or explosion hazard - to protect the substation and working personnel.
- Maintenance and modification capability for cost effectiveness.
- Electromagnetic compatibility to avoid interferences.

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- Capability to be installed on the site.
- Protection against environmental condition to the assembly circuit - used to check corrosion and damage of electrical part.
- Capability to operate the electrical installation.
- Shunt trip requirement.
- Ground fault protection.
- Interlocking system to avoid unauthorised access.
- Fuse

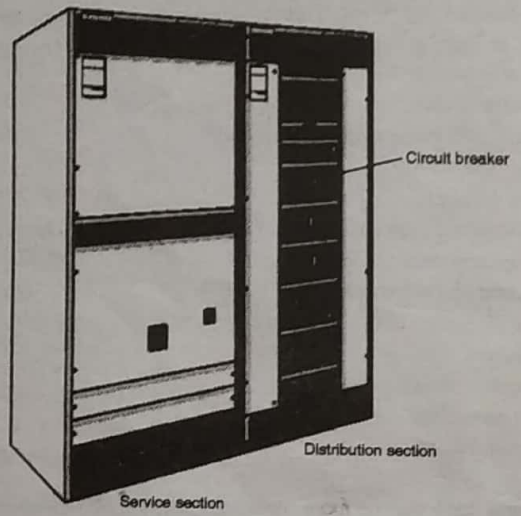

Fig. 3.3.1

3.4 Motor Control Centres (MCC)

Motor control center are having following electrical equipment's.

- Main bus bar
- Earthing bus bar
- Incoming busbar circuit breaker
- Outgoing switching devices
- Fuses
- Safety interlocking devices
- Protective relays
- Control and monitoring devices
- Communication or network interfacing devices
- Terminal compartment

Motor Control Centres are having following features used to reduce the possibility of arc-flash incidents and injuries in motor control centres

- Component Rejection features – it ensures compatible components are used as a system.
- Voltage Test Points – it provides point of testing for presence of voltage outside the unit
- Correctly applied torque to electrical joint connections

- IP20 - Finger safe – it prevent exposure of live parts
- External Voltage Indication
- Proper Component Selection – it ensure properly rated components used in the system.
- Labyrinth Bus shutters - Provide isolation of bus with shutters wherever possible
- Remote Racking Mechanism - Provide capability of racking the unit in/out outside of the arc-flash boundary
- Correct Instruction Materials - Provide correct and adequate instruction material
- Use Current limiting Interrupters - Fuses and High interrupting breakers shall be used

3.4.1 Selection Criteria for Motor Control Centres

- Electrical shock resistance compartments and enclosures
- Proper physical access to human operators
- Smaller and simpler construction
- Rigid barriers
- Separation of bus bar and terminations
- Cost and economic factors
- Single and duplicate bus bar system
- Safety interlocking devices (both mechanical and electrical)
- Proper control and indication devices to avoid human operator error
- Good Man Machine Interface
- Availability of battery or uninterruptible power supply (UPS)
- Availability of under voltage relay
- Availability of serial communication network equipment
- Electromagnetic interference
- Microprocessor based system for better control
- Arc flash hazard preventive assembly which can be arc resistant system, ground fault protection system.

3.4.2 Benefits of Motor Control Centres

- Equipment size gets reduced resulting lower civil, capital and installation costs.
- Due to simple design time required for design, manufacture, installation and commissioning get reduced.
- By carrying out preventative maintenance working life can be increased.
- Reduced maintenance cost.
- Higher working personnel safety due to computerized control.

3.5 Selection of Protection System

- Protection system should be necessary to provide reliable electric power to the consumers. Here we are assessing the selection criteria for selection of protection system.
- In case of distribution network we requires :
  1) Current differential protection
  2) Balanced voltage protection
  3) Fault generated noise protection
  4) Phase comparison protection
  5) Over current protection.

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3.5.1 Selection Criteria for Protection System

- Protection to operating persons against indirect contact.
- Protection of persons under emergency conditions.
- Protection against fire.
- Immunity against lighting strikes, electromagnetic interference, electric arc etc.
- Protection against voltage dips during insulation failure of components.
- Lesser maintenance cost and repair cost.
- Low cost.
- Earthing system used.
- Must have facility which is rapid and automatic in nature to disconnect the faulty item/section of electric network.
- Lesser disconnection of healthy electric network.
- Larger discrimination property.
- Less operating time.
- High stability during fault conditions both external and internal faults.
- Backup protection scheme.

3.6 Coordination and Discrimination

- For better co-ordination and discrimination we have to use computer based power management systems. If involve components like SCADA, PLC, Component automation etc.
- Actual discrimination limits the part of installation affected by the fault.

3.6.1 Objectives

1) Minimize extent fault
2) Minimize the service interruption due to faults.
3) Minimize the duration of outages.

3.6.2 Discrimination classification

- Current discrimination
- Time discrimination
- Energy discrimination
- Zone selective interlocking

3.6.3 Benefits of better co-ordination and Discrimination

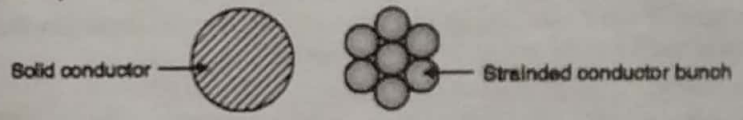
- Improved accuracy of plant measurement
- Better control over processers
- Better two-way communication
- Most reliable operations
- High speed load shedding
- Better condition monitoring of electrical components
- Data logging and archiving of data
- Fault outage durations get reduced

- Service interruption get reduced
- Unnecessary maintenance get reduced with their cost
- Helps in carrying out reliability centered maintenance (RCM) program
- It increases the operational life of equipments
- Better power system reliability.

3.7 Cable and its size

3.7.1 Cables

- Cables are generally used in underground systems which are buried underground.
- There are various types of cables used
  - Solid conductor
  - Multi strand conductor
- In case of solid conductor copper or aluminium or alloys are used as a conducting material. In case of multi strand conductor a small cross-section bunched conductors are placed together. This gives flexibility to the cable.



- Additional mechanical strength is provided by metallic armouring around conductors.
- Cables are used in following cases
  (i) In largely populated areas to avoid risk of shocks.
  (ii) In power plants and substations where maintenance activities restrict the use of overhead lines.
  (iii) The current carried by the conductors produce heat causing large increase in temperature

3.7.2 Classification of Cables

- Cables are broadly classified into two categories:
  (a) As per the type of insulating material used in manufacturing the cables
  (b) As per the voltage rating of the service
- The cables can be classified as
  L.T. (Low Tension) Cables – used upto 1000 volts (1 kV)
  H.T. (High Tension) Cables – used upto 11,000 volts (11 kV)
  S.T. (Super Tension) Cable – used from 22 kV to 33 kV
  EHT (Extra High Tension) Cables – used 33 kV and above

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3.7.3 Construction of Cable

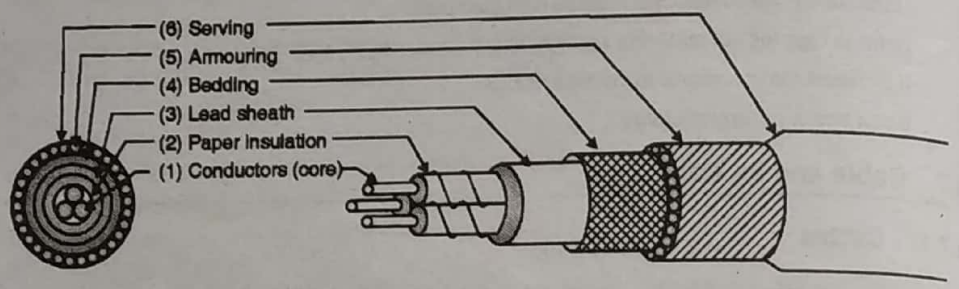

Fig. 3.7.1 : General construction of underground cable

Figure shows the general construction diagram for cable having various sections

1. **Cores or conductors**

   Conductors are made of Copper, aluminum or tin etc. with strained in nature to have flexibility for pulling / laying.

2. **Insulation**

   The insulating material used may be (i) Rubber, (ii) Impregnated paper, etc. Thickness of the insulation is decided by the voltage level where it is used.

3. **Metallic sheath**

   It is either of aluminium or generally lead surrounding the insulation. This protects the conductor and insulation from moisture, acids, alkalies, etc.

4. **Bedding**

   In order to avoid corrosion of aluminium or lead sheath, the sheath is covered with jute fibres material. This also safeguards the sheath from metallic armouring from having mechanical injuries.

5. **Armouring**

   Sometimes it is possible that cable get damaged during handling, pulling or laying. In order to avoid this and protect the cable one more layer in the form of round galvanised steel wires or strips/tape is provided. This layer is called as Armouring.

6. **Serving**

   It is a layer of impregnated hessian tape. It provides protection to the armouring. Some cables may not have armouring. The layers of bedding, armouring and serving are the protective layers to the cable.

3.7.4 Cable Insulation

For better operation, working and increased life of cable depends on the insulation material used in the cable so proper choice of insulation material is having great importance.

Following properties are required in the insulation material :

- Resistivity (ρ) should be as high as possible to avoid leakage current.
- Its di-electric strength should be higher to avoid electrical break-down of cable.
- High resistance to moisture so that it should not absorb moisture which protect the cable
- High thermal conductivity so that it passes out the heat to the next layer i.e. sheath.
- High tensile strength to withstanding mechanical injuries while working with cables. It should not get damaged or break.
- It should be non-inflammable and fire proof.
- It should be cheaper in cost
- It should be unaffected by chemical attack like acids/alkalies.
- Copper, aluminium, tin are the most commonly used conducting materials in cables.
- Choice of cross sectional area of cable conductors depends on various factors like.
- Continuous load current.
- Continuous rated current of cable.
- Earth loop impedance
- Short circuit current rating
- Voltage drop across cable under steady state and transient condition.

3.7.5 Factors for Selection of Cable

- Larger operating temperature with high melting temperature.
- High resistance to mechanical wear and tear
- Lower effect of environmental condition and chemical attack.
- Lower damaging effect of steady state and transient over voltages.
- Should withstand freezing temperatures.
- Longer life
- Less maintenance cost.
- Conductors of cable should have low resistance so that voltage drop is less.
- Temperature coefficient of conductor should be low
- Coefficient of expansion should be low
- High dielectric strength
- Low dielectric loss angle
- High insulation resistance
- Good flexibility
- Long service life
- Low flammability
- High resistance to ozone
- Good dimensional stability

3.7.6 Proper selection of Cable

- Improve fire safety
- Increased operational flexibility
- Faster operations of fuses and circuit breakers.
- Increased power quality
- High electromagnetic compatibility of the circuit

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3.7.7 Factors of Cable Sizing

- Ambient temperature
- Cable type and construction
- Cable conductor maximum operating temperature
- Derated cable current
- Motor static load in kW.
- Motor static load power factor
- Motor static load running current
- Type of protection used like fuse, circuit breaker
- Large heat dissipation factor
- Cross section of conductor

3.8 Cable Installation and Management Systems

Some of common installation method includes :

1) **Trenching**

Here cables are buried directly or in the conduit. Trench is digged and cable is installed, backfill is added.

2) **Plowing**

Here cable plow blade breaks up and lifts the earth which feeds the cable. This method is 20 to 40 % less expensive than trenching. Plowed cable has low ampacity.

3) **Thrust Boring**

Here ground surface is drilled under roads for longer distances.

4) **Direct Buried**

Here cables are buried directly in the earth. This the fast and low expensive method for cable installations. The major disadvantages is that cable repair and replacement is difficult.

5) **Conduit**

Use of conduit allows quick repair and replacement. Here conduit can be made up of PVC, steel or fiber glass etc.

6) **Direct buried with a spare conduit**

Here cable is buried with spare conduit for repair or upgradation of cable. A cable can be putted in spare conduit having power carrying capacity.

7) **Concrete - Encased Conduit**

It is most commonly used in urban area where cable and conduit is encased in concrete. Concrete protect the conduit from dig-in damage or collapse of it due to earth shifting.

8) **Preassembled cable in conduit**

A cable with flexible conduit is plow into the ground together. Disadvantage of this method is that it is very difficult to pull the cable after it is grounded. Also the conduit is not mechanically strong.

Due to use of conduit reliability level of power availability is increased. It gives faster repair option. During replacement it does not disturb drive ways, streets, crews. Only disadvantage is that due to use of conduit cost of cable system increases.

3.9 Bus Bar Design

Bus bar

Bus bar is a device which distribute the current to multiple circuit.

Bus bars are arranged in substations in following manner in a substation:

- Single bus bar arrangement
- Single bus bar with sectioning arrangement
- Auxiliary bus bar system
- Ring bus bar system

3.9.1 Single Bus Bar Arrangement

- Fig. 3.9.1 shows the single bus bar arrangement. Here all the incoming and outgoing lines are connected to a single bus bar only. Basic advantages of this system are low cost and less maintenance due to simple construction.

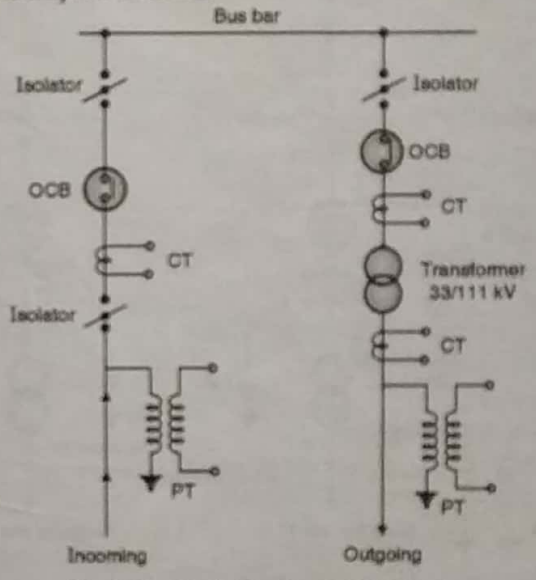

Fig. 3.9.1 : Single bus bar arrangement

- The main disadvantage of this system is that if a fault occurs on the bus bar, then supply gets completely interrupted.

Advantages

- Lesser cost
- Small space is required
- Flexible
- Simple in operation
- Good characteristics for the application of protective relaying

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Disadvantages

- Lowest reliability
- Failure of a bus due to fault result into loss of entire substation
- Maintenance switching is difficult

3.9.2 Single Bus Bar with Sectioning Arrangement

- Fig. 3.9.2 shows the single bus bar with sectioning arrangement.
- Here disadvantages of single bus bar arrangement are lessening. A single bus bar is divided into number of sections and load is equally distributed on all the sections.
- Two near most bus bars are connected with each using isolator. If the fault occurs on any section of the bus bar, then it is isolated using circuit breaker without disturbing the continuity of other section.

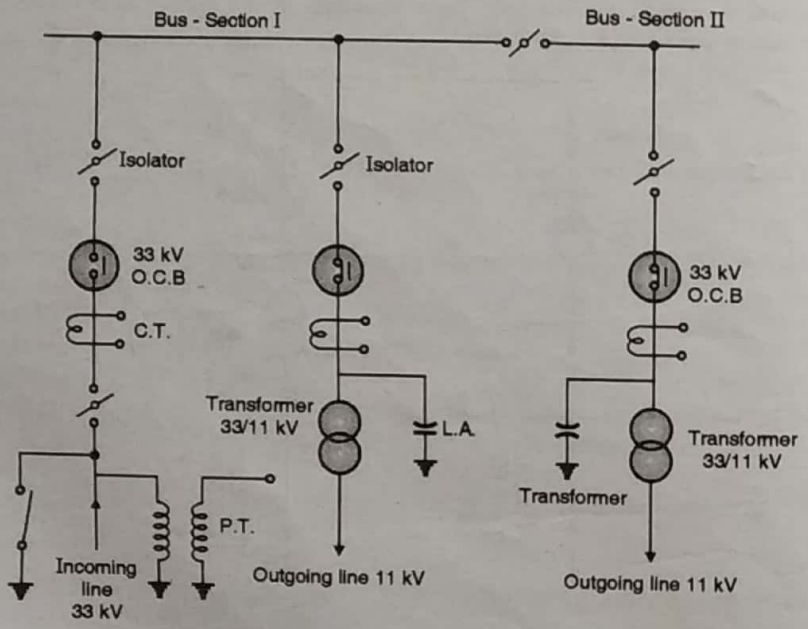

Fig. 3.9.2 : Single bus bar with sectioning arrangement

Advantages

- Flexible in construction and operation
- Provide better isolation of bus sections for carrying out maintenance
- It isolates faulty part of the substation with ease

Disadvantages

- Additional circuit breakers needed for sectionalizing resulting in to increased cost
- **Due to sectionalizing sometimes may result into interruption of non-faulted circuits**

3.9.3 Auxiliary Bus Bar Arrangement

- The arrangement of this system is shown in Fig. 3.9.3. Auxiliary bus bar is provided along with the main bus bar. Main bus bar and auxiliary bus bar can be connected to each other.
- Here entire load can be shared by both the bus bars individually. It is useful in carrying out maintenance work as whole load can be transferred on auxiliary bus bar.

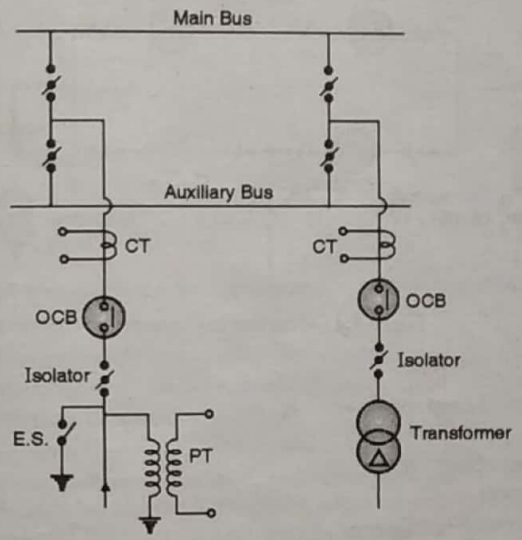

Fig. 3.9.3 : Duplicate bus bar system

Advantages

- Flexible construction and operation
- It gives high reliability
- It provide isolation of bus without interruption of service
- It provide isolation of any breaker for maintenance without interruption of service
- Double feed to each circuit
- Bus fault will not cause interruption of service to any circuits
- Switching is done with circuit breakers

Disadvantages

- Breakers needed for each circuit
- More complicated relaying
- Each circuit need own power source for relaying

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3.9.4 Ring Bus Bar System

- Fig. 3.9.4 shows the required arrangement. It provides high reliability of supply. Here each line is connected with two circuit breakers, where anyone can be used latter on without disconnection of the line.
- The advantage of this is that there always two parallel paths to the circuit and failure of one does not interrupt the supply completely.

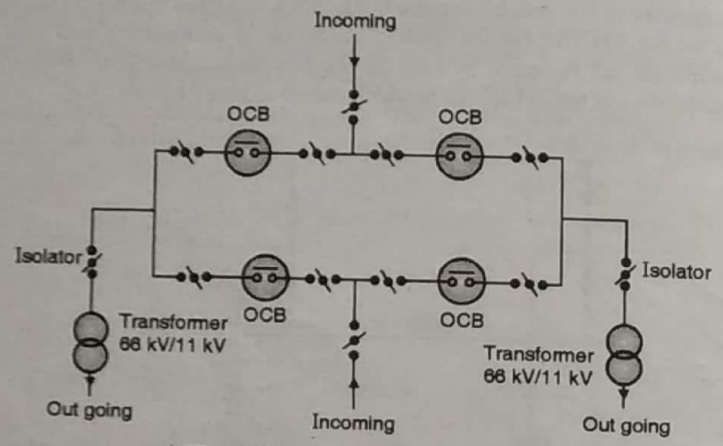

Fig. 3.9.4 : Ring bus bar system

Advantages

- Flexible in construction and operation
- High reliability
- Double feed to each circuit
- Main buses are absent
- Expansion can be possible
- Isolation of bus sections and circuit breakers for maintenance without interruption of circuit

Disadvantages

- During fault isolation of ring circuit part may result into undesirable circuit combinations
- Each circuit require own power source for relaying
- It is usually limited to 4 circuit positions and larger up to 10 in service

3.9.5 Factors Affecting Bus Bar Design

Bus bar design is affected by following factors.

- *Minimum capital cost*
- *Current density should be high*
- *Minimum mass*
- *Less size*
- *Less welding issues*
- *Shape and material of conductor*

- Design of each phase
- Type of insulating support (rool, comb, barrel type supports)
- Required distance between support.
- Ambient temperature (θ_n)
- Permissible temperature rise

$$\Delta\theta = \frac{0.24 \times \rho_{20} \times I^2 \times t}{(n \times s)^2 \times C \times \delta}$$

Where

c - Specific heat of metal
n - Number of bus bar per phase
t - Short time duration
δ - Density of material
ρ_{20} - Resistivity of material at 20°C

- Short circuit current

K - Condition coefficient

$$I = \frac{K \times 24.9\,(\theta - \theta n)^{0.61} \times S^{0.5} \times P^{0.39}}{\sqrt{\rho_{20}\,[1 + \alpha\,(\theta - 20)]}}$$

Where,

$(\theta - \theta_n)$ – permissible temperature rise,
S - Bus bar cross section,
P - Bus bar perimeter,
α - Temperature coefficient of resistance,
ρ_{20} - Resistivity of material at 20° C.

- Electrodynamic forces :

Magnitude of electrodynamic forces depends upon fault current magnitude, shape of the conductors, and securing method. During short circuit or falut very high current are generated leading to damage the conductors of a LV installation, bus bars, cable etc. To avoid damage due to these forces then they are need to be determined by which we choose mechanically size of the conductors and the structures supporting them.

Electrodynamic forces between two parallel busbars which is given by,

$$F = 2 \times \frac{l}{d} \times I_{dy}^2 \times 10^{-8}$$

Where, l - Distance between insulators
d - Phase to phase distance

- Mechanical strength of bas bar which is given as,

$$M = \frac{F \times l}{12} \times \frac{V}{I}$$

Where I/V is the inertia of bus bar

- Resonant frequency which is given as,

$$f = 112 \sqrt{\frac{E \times I}{m \times l^4}}$$

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Where, E - Modulus of elasticity for copper
m - Mass of bar
I - Moment of inertia of the busbar
l - Length between two support

3.10 Basic Selection of Emergency / Backup Power Supplies

3.10.1 Uninterruptable Power Supplies (UPS)

- Inverters are used to convert dc supply into AC supply. These inverter are arranged to provide an uninterruptible power supply.
- Fig. shows, general diagram for UPS. It consists of battery charger, inverter, static switches etc.
- There are three types of UPS available (1) Standby off - line UPS (2) Stand by ferroresonant UPS and (3) online UPS.

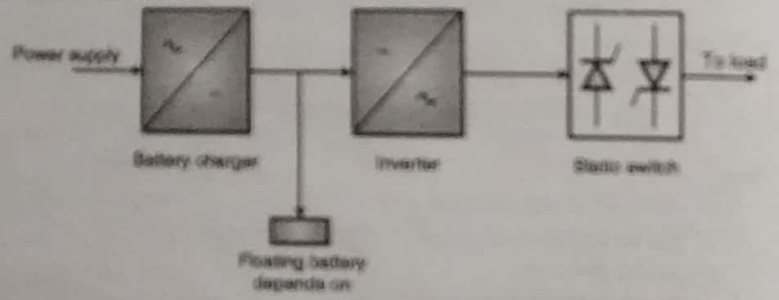

Fig. 3.10.1

Selection of UPS are depends on following factors

- Rated voltage and current of battery and charger system.
- Rated ampere hour capacity of battery and charger system.
- Type of cell used in battery.
- Rate of discharge of battery.
- Overload and short circuit protection
- Type of changer used eg. rectifier or thyristor based
- Harmonic distortion level in voltage and current
- System earthing arrangements
- Electromagnetic compatibility
- Industrial process and their control / monitoring system
- Information and communication technologies
- airports and hospitals requirement
- No break transfer
- Voltage quality for non-linear loads.
- Output power
- Reliability requirement
- Installation maintainability
- Upgradability

- Electrical noise level
- Ventilation requirement
- Frequency variations
- Energy storage capability
- Supply protection level required
- Earthing level required
- Momentary interruptions
- Flickers
- Swells
- Impulses
- Voltage dips / sags

3.10.2 Standby Off-Line UPS

As name suggests these off-line UPS are always remains in standby mode during normal operation. Power is given to directly to the load while supplying power to the battery charger/rectifier. If supply fails, the battery will give power to the inverter which is connected to the load. Have switching delay is of 2 to 4.5 milliseconds after voltage drop below the specified level.

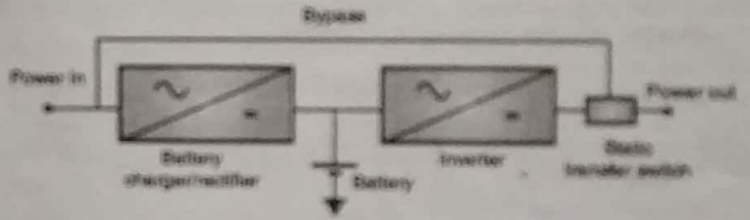

Fig. 3.10.2

3.10.3 Standby Ferroresonant UPS

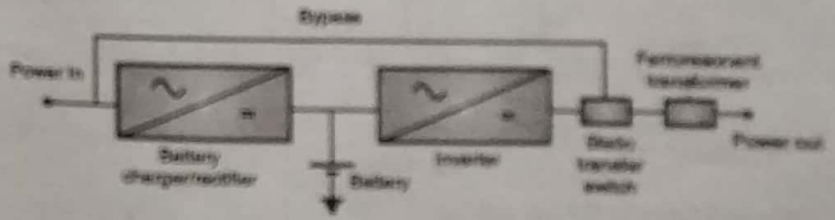

Fig. 3.10.3

Here ferroresonant transformer stores energy from one to several cycles depending on the loading requirement. Figure shows ferroresonant transformer UPS system. Here transformer gives better output voltage regulations and protects the UPS from overload and short circuit conditions. Also it increases battery life. It lowers the maintenance costs.

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3.10.4 On-Line UPS

It is a double conversion UPS. Here power flows from charger/rectifier that supplies power to both a storage battery and an inverter. The inverter generates AC power and feed to the load. In case of power failure the inverter is supplied by the battery. Advantage of this method is that it reduces most power disturbances by filtering. This UPS is sensitive to transients, noise, and power interruption.

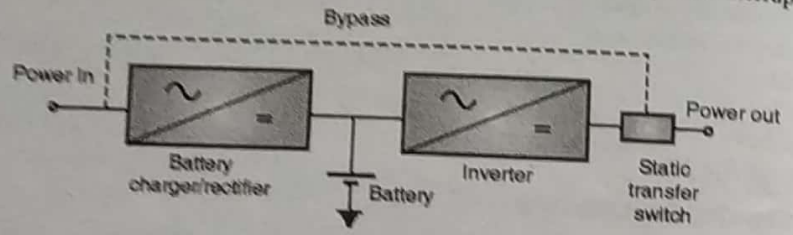

Fig. 3.10.4

3.10.5 Diesel Generator (DG) set

- In DG set diesel engine rotates the alternator to produce electricity or electrical energy. DG set are classified into two types depending on the cycle type.
- 1] Two stoke and 2] Four stroke

A DG set consist of

(1) Diesel engine and its accessories
(2) AC Generator
(3) Switchgear and control system
(4) Connected load

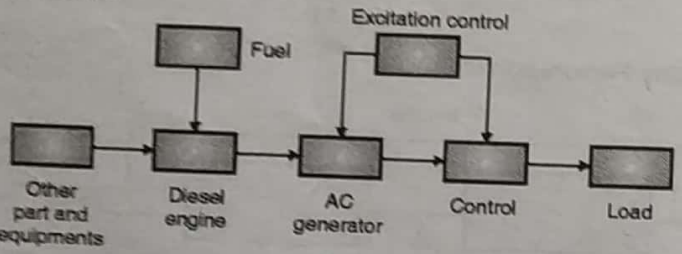

Fig. 3.10.5

3.10.6 Selection Criteria for DG set

- Power of Engine which is calculated from maximum load.
- Speed of Engine which should be either rated speed or near to it.
- Over load capacity
- Wear and tear ability
- Efficiency
- Maintenance and running cost
- Cooling system
- Engine size
- Engine type
- Speed governing
- Installation period
- Start-up time
- Environmental condition
- Fuel quality
- Control system
- Starting equipment
- Ambient temperature
- Altitude
- Humidity
- Drive type
- Load Factor
- Auxiliary power consumption
- Space requirement
- Safety features

Advantages of DG sets are

- Requires less space
- Less installation cost
- **Short start up time**
- Higher efficiency near about 45 - 50 %.
- Suitable for different type of fuels like bio-diesel etc.
- Lesser cooling requirement currently air cooled DG sets are commonly used.

D.G. set characteristics is affected by the load characteristics which are given as follows

- Power Factor - If load is operating at lower power factor it means it require higher excitation currents causing increased losses. For increasing power factor capacitors are placed in load premises.
- Unbalanced Load - due to unbalanced loads on A.C. generator causes unbalanced voltages leading to more heating in A.C. generator.
- Transient Loading – due to transient loading transient voltage dip is produced hampering the operation of D.G. set.
- Special Loads – most commonly used special loads are rectifier / thyristor loads, welding loads, furnace loads etc. these loads are very sensitive towards change in voltage, frequency regulation, voltage wave form etc.

3.10.7 Type of battery

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(1) Lead acid battery (2) Lithium Ion battery
(3) Sodium Sulphue battery (4) Ni-Cd battery

NI - Cd battery

In this cell,

- Positive Ni $(OH)_3$ is used as plate → nickel hydroxide.
- Negative (Cd) is used as plate → cadmium.
- The electrolyte used is 21% solution of potassium hydroxide (KOH) in distilled water.
- The specific gravity of electrolyte is 1.2.

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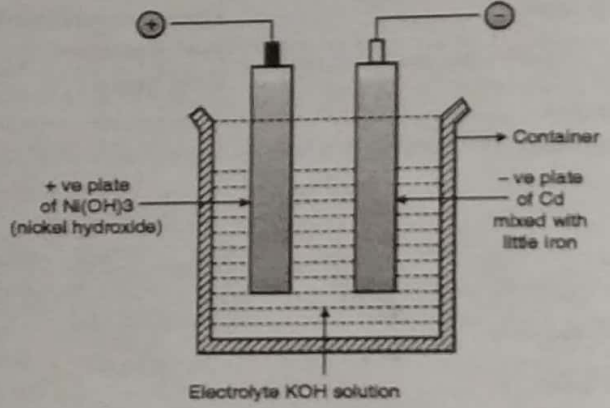

Fig. 1-Q 1(b)

- Little iron as added to Cd to get negative plate.
- The iron prevents the caking of active material and losing its porosity.

Chemical reaction : Here Ni $(OH)_3$ gets converted to lower Ni hydroxide as Ni $(OH)_2$ while cadmium hydroxide Cd $(OH)_2$ gets formed at the negative plate. During charging reverse reaction takes place.

$$2Ni(OH)_3 + 2KOH + Cd \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} 2Ni(OH)_2 + 2KOH + Cd(OH)_2$$

+ ve plate — Electrolyte — – ve plate — + ve plate — Electrolyte — – ve plate

Advantages

1. Due to use of Cd, internal resistance is low.
2. The η are higher than Ni - Iron cell.
3. Compact construction
4. Light in ωt as compared to lead - acid cell.
5. Mechanically strong and can sustain considerable vibration.
6. Less maintenance is required.
7. Gives longer service life.

Disadvantages

1. High initial cost
2. Low voltage per cell of about 1.2 V.

Application

1. In railways for lightening and air conditioning system.
2. In military aeroplanes, helicopters and commercial air lines for starting engines and provide emergency power supply.
3. In electric shaves.
4. In cordless electronic devices.
5. In photo graphic equipments such as movie cameras and photo flash.

3.10.7.1 Batteries

Selection and sizing of batteries depends upon following factor :

- AC voltage sources and voltage level of it.
- Three phase or single phase supply source.
- Battery voltage and capacity of power.
- Normal dc continuous load current.
- Emergency load current.
- Battery discharge rate and levels and recharge times.
- Ambient temperature.
- Altitude
- New/replacement
  - Room size
  - Local variation
  - Voltage
- Duty cycle
  - Temperature correction
  - Aging factor
  - Design margin.
- System voltage
  - Minimum voltage
  - Maximum voltage
  - Recharge voltage
  - Number of cell
- Maintenance requirement
- Ventilation
- Mounting requirement
- Effects of ripple
  - Current
  - Voltage
- Plate type
- Method of charging.
  - Constant voltage
  - Constant current
- Provision for testing and monitoring.
- Float correction factor.
  - Size and weight
  - Load level in MVA
  - Backup time

3.10.8 Calculation of Battery Size

Number of Cells and Cell Voltage

- Number of cells is calculated as the ratio of maximum battery voltage to the float charge voltage

$$\text{Number of cells} = \frac{\text{Maximum voltage}}{\text{Floatcharge voltage}}$$

- The minimum battery voltage is the minimum system voltage. the minimum cell voltage the ratio of minimum battery voltage to the number of cells

$$\text{Minimum cell voltage} = \frac{\text{Minimum battery voltage}}{\text{Number of cells}}, \text{ V/cell}$$

Temperature Correction

As temperature decreases the capacity of a cell also decreases. So it is absolutely necessary to have correction factor.

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Aging Factor

Battery work efficiently throughout its life but at the end of life performance decreases rapidly. For proper operation of battery its initial capacity should be 125 to 135 % of the design capacity.

Design Margin

Battery should have some margin in order to overcome and sustain increased loads, poor maintenance, recent discharge, etc. Normally design margin is taken as 15% to 20%.

Factors used for selection of battery charger are

- Charger efficiency
- Supply power factor
- Time required for full recharge
- Output current rating
- Input voltage rating
- Single phase or three phase input needed
- Current limiting capacity
- Float and high rate voltage setting
- Allowable ripple percentage

Ex. 3.10.1 : Calculate the battery rating for 18 batteries for one hour backup if
DC Voltage - 200 for 5 KVA
End cell voltage / battery - 12 V
Load Power Factor - 1.0
Inverter efficiency - 90%
Capacity utilization – 62 %

Soln. :

$$\text{DC Current} = \frac{\text{UPS (KVA)} \times 1000 \times \text{Load power factor (= 1)}}{\text{Inverter efficiency} \times \text{End Voltage}}$$

$$= \frac{(5 \times 1000 \times 1)}{(0.9 \times 12 \times 18)} = 25.72 \text{ A}$$

$$\text{Capacity of Battery (AH)} = \frac{\text{DC Current} \times \text{Duration in Hrs}}{\text{\% age Capacity utilization}} = \frac{(25.72 \times 1)}{0.6} = 42.9$$

$$\text{VAH} = \text{AH} \times \text{Nominal voltage} = 18 \times 12 \times 28 = 6048$$

3.11 Preliminary Design of Inertial Lighting System

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Efficiency of Interial lighting system depends on following parameter

- Interior lighting power density.
- Lighting design.
- Effective Maintenance.
- Use of proper lighting devices.
- Reflectance by various room surfaces.
- Glare reduction.

- Uniform light distribution.

Inertial lighting system design calculation procedure is as follows :

(1) Find the recommended level of illumination depending on the activity to be carried out from recommended luminance for different types of lighting.

(2) Find area and physical characteristics of the room to be illuminated

(3) From above data get the average illumination needed.

(4) Find out the necessary light flux from which calculate the power of the lamps, the number of lighting points and layout of the light fittings.

so total light flux is given as,

$$\phi_t = \frac{E \times S}{ER \times EF \times FM}$$

Where, ϕ_t = Total light flux (lumen)
E = Average luminance (Lux)
S = Surface to be illuminated
ER = Efficiency of room
EF = Efficiency of light fitting
FM = Maintenance factor of light unit

- Average luminance is calculated from activity required.
- EF should be provided by the maker.
- ER it depends on its dimensions and reflection factor of ceiling (R_c), the walls (R_w), floor (R_f) and on room index factor (k)

(5) Calculate Room index Factor k which is given as

$$K = \frac{L \times W}{h\,(L + W)}$$

Where, L = Length of room
W = Width of room
h = Distance between work level and light fitting

(6) Calculate maintenance factor (F_m) which is based on the loss of light due to natural aging, dust and reflection losses from light bulb. This factor can have values from 0.5 to 0.8

(7) Calculate the lighting fixtures which given as the ratio of total necessary flux with nominal light flux.

$$N = \frac{\phi_t}{\phi \times n}$$

Where, N = Number of lighting fixtures
ϕ_t = Total light flux
ϕ = Nominal light flux of lamp
n = Number of lamps in lighting fixture.

(8) Calculate number of luminaries along which is given as,

$$= \sqrt{\frac{L \times N}{W}}$$

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(9) Calculate the number of luminaries across which is given as,

$$= \sqrt{\frac{W \times N}{L}}$$

Ex. 3.11.1 : Calculate interior lighting calculation for a room having following data - Length of room (L) = 10m, Width of room (W) = 8m, Height of room (H) = 4m, Height of work level = 0.85 m Reflection factors - Ceiling (R_c) = 80%, walls (R_w) = 50 %, Floor (R_f) = 30%, Average luminance = 800 lux Type of light - Fluorescent tube with 2000 lumen, Type of lighting fixture RML 44, h = 3.5 m, n = 10.

Soln. :

$$\text{Room index (k)} = \frac{L \times W}{h(L+W)} = \frac{10 \times 8}{3.5 \times (10+8)} = 1.269 = 1.27$$

Let, efficiency of room (ER) = 0.9

efficiency of lighting fixture (EF) = 0.6

Maintenance factor (F_m) = 0.8

$$\text{Total necessary flux } (\phi_t) = \frac{E \times S}{ER \times EF \times F_m} = \frac{800 \times L \times W}{0.9 \times 0.6 \times 0.8} = \frac{800 \times 10 \times 8}{0.9 \times 0.6 \times 0.8} = 148148.148$$

$$\text{Number of lighting fixtures} = \frac{\phi_t}{\phi \times n} = \frac{148148}{2000 \times 10} = 7.407 = 8 \text{ lighting Fixtures}$$

$$\text{Number of luminaries along} = \sqrt{\frac{L \times N}{W}} = \sqrt{\frac{10 \times 8}{8}} = 3.16 \text{ take } 3$$

$$\text{Number of luminaries across} = \sqrt{\frac{W \times N}{L}} = \sqrt{\frac{8 \times 8}{10}} = 2.53 \text{ take } 3$$

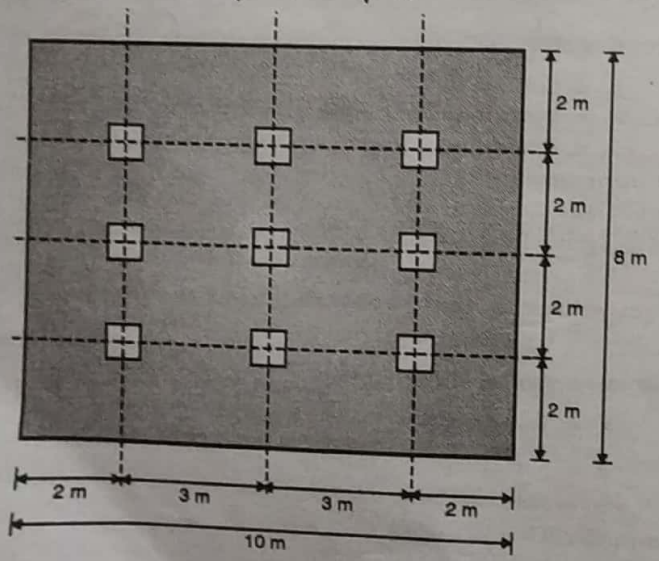

Fig. P.3.11.1

Ex. 3.11.2 : A sewing factory is to illuminated at 500 lux. The hall measures 30 m × 20 m × 5m. Calculate number of fixtures required and also draw lighting layout. Different design consideration made.

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Soln. :

$$\text{flux } (\phi) = \frac{EA}{\eta P}$$

$$E = 500 \text{ lux}, \quad A = 30 \times 20 = 600$$

Let coefficient of utilization (η) = 0.8

Depreciation factor = 0.9

$$\therefore \quad \phi = \frac{500 \times 600}{0.8 \times 0.9} = 416{,}666.7 \text{ lm} = 416{,}667$$

Let luminious efficiency = 24

$\therefore$ Flux emitted / lamp = 500 × 24 = 12,000

$$\text{Number of fixtures} = \frac{\phi}{\text{flux emitted / lamp}} = \frac{416{,}667}{12000} = 34.7 \approx 35$$

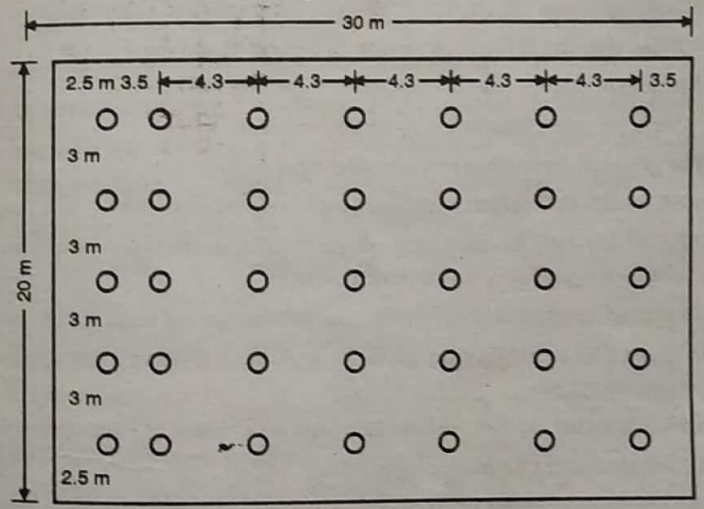

Fig. P.3.11.2

Different design considerations

- Coefficient of utilization
- Depreciation factor
- Flux emitted by the lamp
- Type of lamp or tube or illumination device
- Luminious efficiency
- Spacing between fixtures
- Clearance on side walls

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3.12 IS Standards Applicable in Designs

- IEC 60439 describes the selection of LV switchgear
- IEC 60632 describes the selection of HV switchgear
- IEC 439-1 explains the LV switchgears and control gears assemblies
- IEC 60947-3 is useful to understand clearance between contacts, creep age distance, over voltage withstand capability of switch gears
- IEC 61439-1 and 2 provides information about switch board, used in electrical systems
- BSEN 60439-1 explain rating and equipments used in motor control centres
- IEC 60287 used to understand current carrying capacity of cable
- IEC 60183 gives guidance on the selection of cables for HV systems
- IEC 60502 provides information about sheathing material used in cable and steel armouring
- IEC 60364 provides cable rating data and installation guidelines of cables
- IEC 60228 provides brief information about classes of copper and aluminium used in cables
- IEC 60909 describes the short circuit currents in 3 phase ac systems
- IEEE 1584 used to describes the arc flash hazards information
- IEC 721-3-3 is providing information about anticorrosion
- IEC 60038 gives standard voltages for electrical equipments
- ANSI/IEEE std 485-1983 defines battery size used in electrical system
- ANSI/IEEE std 484-1987 describes practices for installation design and installation of large load storage batteries for generating stations and substations
- IEC 6227 explain information of circuit breaker, disconnector and earthing switches
- ANSI/IEEE std C57.105-1978 gives guide for application of transformer connections in three phase distribution system
- IS 1255-1983 describes the code for installation and maintenance of power cables
- IS 3646-1992 gives codes for interior illumination
- IS 10118-1982 gives codes for selection, installation and maintenance of switchgears and control gear
- ANSI CI 12.20 and IEC 62053-22/23 describes the standards for power accuracy
- IEC 61850 describes the communication standards for substations.
- IEC 865 describes short-circuit currents calculation and their effects.
- IEC 909 describes factors used considered for the calculation of short-circuit currents in three-phase a.c. systems.
- IEC 1117 gives information about the method for assessing the short-circuit withstand strength of partially type-tested assemblies (PTTA).

Review Questions

Q. 1 Explain selection factor considered in HT/LT switchgears.
Q. 2 Discribe selection factor considered in emergency/backup supplies.
Q. 3 Explain selection factor considered in metering system.
Q. 4 Discribe selection factor considered in switchboards.
Q. 5 Explain selection factor considered in motor control centres.
Q. 6 Discribe features of motor control centres.
Q. 7 Explain selection factor considered in protection system.
Q. 8 Discribe benefits of better co-ordination and Discrimination.
Q. 9 Explain properties required in the selection insulation material in cables.
Q. 10 Discribe factors on which cable sizing depends.
Q. 11 Explain common installation method used for irrection of cables.
Q. 12 Discribe commonly used busbar arrangements.
Q. 13 Explain selection factor considered in busbar design.
Q. 14 Discribe selection factor considered in Uninterruptable Power Supplies (UPS).
Q. 15 Explain selection factor considered in Diesel Generator (DG) set.
Q. 16 Discribe selection factor considered in Selection and sizing of batteries.
Q. 17 Explain interial lighting system design calculation procedure.
Q. 18 Discribe IS standards used in designing of switchgear protection & auxillary system in electrical systems.

3.13 University Questions and Answers

May 2016

Q. 1(b) Explain any one type of battery. *(Ans. : Refer section 3.10.7)* **(5 Marks)**

Q. 5(b) A sewing factory is to illuminated at 500 lux. The hall measures 30 m × 20 m × 5m. Calculate number of fixtures required and also draw lighting layout. Different design consideration made. *(Ans. : Refer section 3.11)* **(10 Marks)**

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